

**STORAGE
BEHAVIOUR
OF
SWEET ORANGES
AND
MANDARINS**

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Storage behaviour

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STORAGE BEHAVIOUR OF SWEET ORANGES AND MANDARINS

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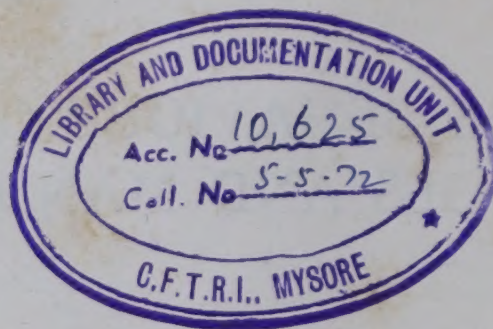


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CONTENTS

	<i>Page</i>
Preface	iv
I. Introduction	1
II. Review of Literature	5
III. Fruit Material, Equipment and Experimental Plan	18
IV. Optimum Storage Temperature for 'Coorg' and 'Nagpur' Mandarins and 'Sathgudi' Sweet Orange	29
V. Effect of Storage Temperature on Colour Development in 'Sathgudi' Sweet Orange	70
VI. Optimum Temperature Combination for Storage and Colour Development of 'Sathgudi' Sweet Orange	73
VII. Effect of Fruit Size on Keeping Quality of 'Coorg' Mandarin and 'Sathgudi' Sweet Orange	77
VIII. Effect of Method of Picking on the Storage Life of 'Coorg' Mandarin Orange	80
IX. Effect of Orchard Variability on the Cold Storage Behaviour of 'Coorg' Mandarin Orange	81
X. Economics of Cold Storage Practice in 'Coorg' Mandarin Orange	88
XI. General Considerations	92
Literature Cited	103

PREFACE

The problems of production and preservation of citrus fruits in India are at present engaging the attention of the researchers in different parts of the country. Pioneer work on cold-storage preservation of citrus fruits was undertaken during the late thirties at Lyallpur (now in Pakistan) and Kirkee near Poona in Maharashtra State. The author, who had worked at Lyallpur, got an opportunity to extend his earlier investigations to orange varieties grown in south and central India while working at the Central Food Technological Research Institute, Mysore.

These investigations aroused considerable interest among the orange growers of Coorg where orange commands importance next to the cash crop of coffee. Some of the progressive members of the Coorg Orange Growers' Co-operative Society supplied fruits free of cost for an assessment of the cold-storage behaviour of the fruits raised in their orchards. The 'Coorg' mandarin orange was an object of more detailed study. Similar investigations were simultaneously undertaken on 'Nagpur' orange which is extensively grown in central India, and is claimed to be the best mandarin orange of the world. These studies would not have been complete if the sweet orange was not included for comparative evaluation and, therefore, the most popular variety 'Sathgudi' sweet orange was included in the study.

The results of these investigations are embodied in this bulletin. An endeavour has been made to give an integrated picture of the cold-storage behaviour of the various orange varieties grown in different parts of India under varying soils and climatic conditions.

I am extremely thankful to Dr P. B. Mathur, formerly Head of the Division of Storage and Preservation, Central Food Technological Research Institute, Mysore, who has been a constant source of guidance throughout the course of these investigations and to Dr V. Subrahmanyam, the then Director, Central Food Technological Research Institute, Mysore, for his keen interest and encouragement.

Thanks are also due to the members of the Coorg Orange Growers' Co-operative Society, Pollibetta for their co-operation and supply of fruit material free of cost for this study, and to the Council of Scientific and Industrial Research, India, under whose auspices the investigations reported in this thesis were undertaken.

I. INTRODUCTION

India is inhabited by people mostly vegetarian in dietary habits. The normal vegetarian diet does not supply the body all its requirements for growth and health. To bring it to the level of adequate balanced diet, supplying all the required vitamins and minerals, supplementation with fruits has been considered very necessary.

Fruits, because of their prohibitive prices, have so far been considered an item of luxury in a man's diet. The urgency of making them an essential part of a vegetarian diet had now been fully realised and efforts are being made to increase the production of fruits by having more orchards and devising ways for proper storage and transportation to avoid spoilage. In the Second and Third Five-Year Plans, therefore, emphasis has been laid on raising the production of fruits and vegetables.

Elaborate horticultural schemes have been launched under which expert technical advice and necessary wherewithal are being provided on long-term basis to persons interested in the development of horticultural crops. Horticultural research has also been organised on a regional basis all over the country to improve and expand fruit cultivation on sound and scientific lines.

No doubt, mango is the national fruit of India, but recent trends in horticultural development are more in favour of citrus fruits. Already huge citrus plantations are coming up in certain parts of India. It is a fascinating sight to observe individual citrus orchards running into hundreds of acres at a stretch and planted with approved varieties according to design. The area under citrus fruits is expected to rise further in view of the valuable part fruits can play in a vegetarian diet.

India abounds in citrus species and their horticultural forms, and is considered to be the native habitat of many of them. Of all the citrus species widely cultivated in this sub-continent the oranges are commercially the most important occupying about 70 per cent of the total acreage under citrus fruits. Two species of orange, viz. *Citrus reticulata* Blanco and *Citrus sinensis* Osbeck are commonly grown in India. The former species, comprising several varieties of the loose-jacket mandarin like 'Nagpur', 'Coorg', 'Desi' (Punjab), 'Burnihat' and 'Khasi' (Assam), is very popular. On account of its wide range of adaptability it has established itself in far-flung regions scattered all over India (Fig. 1). Recently, however, the latter species comprising several important varieties of sweet orange, namely 'Blood Red', 'Pineapple', 'Valencia Late', 'Washington Navel', 'Jaffa', 'Hamlin',



Fig. 1. Distribution of mandarin oranges, sweet oranges and sour limes in India.

etc., is gaining ground in new plantations which are extending fast in the semi-arid areas owing to increased irrigation facilities. With such a wide array of orange varieties grown under different agro-climatic conditions, the magnitude of variation in fruit form and its composition is bound to be tremendous.

Although tropical in origin, citrus has been domesticated in sub-tropical as well as in warm temperature regions. Because of its adaptability to different soil and climatic conditions, citrus species have been found growing on sandy and gravelly soils in the hilly and humid regions of Assam with 254 cm of annual rainfall and at altitudes of about 608 m. Around Nagpur in Maharashtra, it grows well at an elevation of 304 m to 364 m with 110 cm of annual rainfall supplemented by artificial irrigation. In the adjoining areas of Khandesh, oranges are grown at an elevation of 425 m to 608 m under much drier conditions with 75 cm rainfall combined with artificial irrigation. The soils in Nagpur and Khandesh areas are heavy, black and well-drained. Further south in Mysore, Madras, Kerala and Nilgiris oranges are grown on deep, well-drained, black or red loamy soils under an annual rainfall of 152 cm (sometimes up to 254 cm) and at altitudes ranging from 608 m to 1520 m. In the north, cultivation of mandarin oranges is confined mainly to the submontane tracts of the Punjab and Uttar Pradesh up to an altitude of 608 m with 152 cm of rain. The soils here are light loam. The sweet orange, however, finds a more suitable habitat in the drier and hotter parts of these States under irrigated conditions.

Climatic conditions in India are not suitable for keeping the picked fruit for a long time. The defective methods of picking, packing and handling further affects the keeping quality of the fruit. Nearly 15 to 20 per cent of the production is wasted in the producing areas, owing to lack of adequate transport and other allied bottlenecks. This creates a paradoxical situation of scarcity and waste, which is likely to accentuate with the anticipated boom in fruit production unless necessary measures are taken in time.

Researchers in other countries have done considerable work on the cold-storage problems of citrus fruit but these findings have limited application under our conditions. Further, different varieties of several species of citrus are grown in particular areas endowed with special agro-climatic conditions favourable for these varieties. Even within the variety zones, the cultural and manurial practices are found to differ widely. Since the conditions under which a fruit is produced and picked are known to exercise profound influence on its keeping quality. There could not obviously be a simple solution to the complex problems indicated above. Appropriate storage requirements

for each condition have got to be determined experimentally before they can be applied with certainty. The present investigations were, therefore, undertaken in this context with a view to determine the optimum storage temperature, storage life and keeping-quality, the nature of physico-chemical changes occurring during storage and finally the economics of the cold-storage practice for mandarins and sweet oranges grown under a variety of conditions in this country.

II. REVIEW OF LITERATURE

Storage Temperature for Sweet Orange. Earlier work on the cold storage of oranges has been reviewed extensively by Wardlaw (1937). Briefly, the investigations of Adam (1923) on 'Washington Navel' and 'Valencia Late' oranges in Australia indicated that 34°F was the most favourable storage temperature. Tindale (1927a), also working in Australia, employed a range of storage temperatures from 34° to 40°F on 'Valencia Late' orange and concluded that 37°F was the most suitable temperature for this variety. He observed chilling injury on fruits at 34°F but not at 36°F after a storage of four months. In 'Washington Navel' orange, Tindale (1927b) tried a range of storage temperatures from 32° to 40°F and found that the fruit of this variety could be held in good condition up to three months at 36°F. Lower storage temperatures caused skin blemishes and breakdown similar to the 'Valencia Late'. Later, Young and Read (1930, 1931) found that 'Valencia' orange grown in Australia could be kept for three to four months at 38°F without practically any loss. They also showed that 'Navel' orange stored best at 45°F. At this temperature the fruit showed no signs of deterioration after 15 weeks. The flavour remained normal and the total wastage was only five to six per cent. On the other hand, the fruit of this variety stored at 32°F acquired a bitter taste after five to six weeks. After 11 weeks of storage, bitterness became much more marked and the fruit showed a collapsed appearance, the skin becoming dull and discoloured.

Working on marine refrigeration of Californian oranges, Overholser (1930) found that the temperature range of 36°-39°F was most satisfactory. Higher storage temperatures caused shrivelling of the fruit and excessive losses from decay, whereas lower temperatures resulted in pitting of the rind. Friend and Bach (1932) investigating the storage behaviour of Texas-grown citrus fruits observed that 'Valencia' orange could be kept satisfactorily at 32°F for 20 weeks. This variety proved to be the best keeper of all the Californian varieties tried. The superb storage performance of 'Valencia' oranges was also confirmed by Rose *et al.* (1933). They reported that oranges could be stored for one or two months at 32°F without deterioration in appearance or flavour.

Wardlaw (1933) and Wardlaw and Leonard (1934) working on different varieties of sweet oranges grown in the West Indies discovered 40°F as the most suitable temperature. But in Florida, Stahl and Camp (1936) found 37.5°F as the optimum storage temperature for unwrapped and untreated fruit of the 'Pineapple' and the 'Valencia Late' varieties of sweet orange. The period of marketability or post-

storage life was also found to be better in fruit stored at 37.5°F than the one stored at 32°F. The studies of Van der Plank *et al.* (1937, 1938) on oranges in South Africa revealed that low wastage with best flavour could be maintained at 39°F. Wastage was equally low when fruit was stored at 50°F but after about two months the fruit tended to become stale.

In the detailed investigations of Trout, Tindale and Huelin (1938) in Australia, 'Washington Navel' orange picked in early June from Merbein remained palatable for 12 weeks at 40°-42°F. In Merbein and Lockington, storage temperatures of 40°F also gave the best results with 'Valencia Late' orange picked in mid-December, recording a storage life of 14 weeks. On the other hand, Williams (1938), another contemporary worker in Australia held that oranges stored at 36°-38°F kept much better than those at lower or higher temperatures. Bitterness and brown stains appeared particularly if fruit was kept at 32°F. Of the four varieties tried by him, 'Valencia Late' kept best for 11 weeks at 36°F.

Huelin (1942) stated that in spite of a large number of experiments the problem of the most suitable temperature for long periods of storage and transport still remained a matter of extreme difficulty. In his opinion, this was largely owing to the complex origin of storage spot. The tendency for the maximum development of rind blemishes at lower temperatures (37°-40°F) appeared when the fruit had to be stored for eight weeks or more. He suggested that there was considerable amount of 'latent injury' even after four weeks at 37°F and 40°F, and that better results might be obtained by an initial holding at 50°F followed by storage at 40°F. Early occurrence of this 'latent injury' at low temperature was possibly recognised by Anon (1954) who recommended that 'Navel' and 'Valencia' oranges, if not ethylened, might be held in precooler at 36°-38°F for a period not exceeding three weeks before transshipment. Miller (1946a, b) also observed that pitting occurred in oranges at 36°-40°F, although reviewing the physiology of citrus fruits in storage he stated that recommended temperature for oranges was 34°-37°F.

Ryall (1947) found that 'Valencia' orange grown in Texas retained good quality for four months when stored at 38°-40°F except that it showed some aging around the stem. Fruit held at 32°-34°F showed greater deterioration.

Reporting on the storage behaviour of 'Navel' and 'Valencia' oranges in Victoria (Australia), Tindale (1950) pointed out the important bearing of stock-scion relationship on the keeping quality of these fruits. 'Navel' oranges on Citronelle (rough lemon) root-stock stored for one to two months at 45°F showed more wastage than fruit of the same

variety on sweet orange, sour orange and trifoliate root-stocks. Also, 'Valencia' orange fruit on trifoliate stock showed less wastage after two to three months than fruits from trees on the other three root-stocks.

Metlickii (1954), discussing the basic problems of the biology of fruit storage in the U.S.S.R., recommended a general storage temperature of 5°C (41°F) for oranges.

Tindale and Pegg (1955) have shown that the flavour of untreated 'Washington Navel' fruit stored at 32°F rapidly deteriorated and was only fair after four weeks. Mould wastage was, however, negligible at this temperature even after eight weeks. The incidence of cold storage disorders was the greatest at 35°F and appeared within six weeks in early picked fruits. Few disorders occurred at 40°F with a storage period of one to two months.

According to De Fossard (1959), for cold storage, fast cooling was the best for orange fruit which received the present-day packing house treatment, but for fruit handled more quickly slower cooling gave better results. Fruit should reach the right storage temperature within two days of its arrival at the cold store. Constant temperatures between 40° and 45°F as well as high humidity are necessary.

Chace and Harding (1962, 1963) observed that Pope's 'Summer Orange' stored for two or three months at 32°F developed much less decay and rind breakdown during the subsequent seven days at 70°F than fruit stored at 38°F.

Reig and Albert (1966) found that 'Washington Navel' oranges were more suited than 'Navelete' for cold storage and results were better at 2°C and 85 per cent R.H. than at 4°-5°C and 70-75 per cent R.H. Post-storage deterioration was reduced by 24 hours at 8°-10°C between cold storage and marketing.

Storage Temperature for Mandarin Orange

Cold storage studies conducted on mandarin orange (*Citrus reticulata* Blanco) are fewer than those on sweet orange (*Citrus sinensis* Osbeck). The former species, of course, engaged the attention of researchers wherever it presented a storage problem of its own.

Leonard and Baker (1934) found that the 'King' orange or 'Giant' mandarin grown in the West Indies could be stored at 45°F for 60 days with negligible wastage. At 50°F fruit was still attractive externally but lost all traces of acidity and flavour. The juice was insipid, sweet and watery. Similarly, Chen (1934) working on mandarins grown in China reported that loose-skinned oranges became insipid in flavour after four months' storage at 5°-12°C (41°-54°F) and 90 per cent humidity. After five months the pulp became dry and shrunken although externally the peel appeared normal.

For mandarins grown in Australia, Williams (1938) observed that they could be stored well for eight weeks at 40°F. The best keeping mandarins for storage were the 'Thorny' having thin skin and well-packed fruits with a decidedly pleasing flavour. Hall (1938), another Australian worker, also stated that the best general storage temperature for untreated mandarins might be 40°F. He added that 'Emperor Mandarin' has a shorter life than 'Navels' or 'Valencias' and it broke down more rapidly after removal from cold storage. The 'Ellendale' variety which was a late-maturing and more solid type of mandarin than the 'Emperor' kept much better. He also observed that mandarins were less susceptible to storage spot than sweet oranges. During the comprehensive studies of Huelin (1942) on Australian citrus fruits it was found that wastage in 'Emperor Mandarin', stored at 37°F, 40°F and 45°F, was definitely less at 40°F and 45°F than at 37°F. Storage life at 40°F was eight weeks as compared with six to seven weeks at 45°F.

Fujita *et al.* (1953) reporting on the effect of temperature and humidity on the storage life of 'Satsuma' mandarin grown in Japan observed that storage at 5°C (41°F) and 85 per cent humidity gave the lowest weight loss, the lowest rate of rotting, the least change in specific gravity and least calyx discolouration, but colour development was not good.

Metlickii (1954) recommended a storage temperature of 3°C (37.5°F) for mandarins grown in the USSR.

According to Soost and Cameron (1955) 'Kara' mandarin grown in California could be stored in good condition for three weeks. At 43°F the amount of decay was lower and the physiological characters of the fruit slightly better than at 53°F.

Reig and Albert (1966) carried out storage studies on 'Satsuma' and 'Clemenule' mandarins for 90 days under two conditions, viz. (i) 1°C, 85-90 per cent R.H. and 15 minutes' air renewal per day, and (ii) 4°-5°C, 85-90 per cent R.H. and no air renewal. They found that conditions in (i) were more satisfactory than those in (ii) and waxing was an advantage. 'Satsumas' retained a very good quality for 30 days and 'Clemenules' for 45 days.

Cold-Storage Studies on Oranges in India

Cold-storage studies on mandarins have also been carried out in India from time to time in view of their top position among the citrus fruits grown in this country. Locally important varieties of sweet oranges were also included by some workers in their studies.

Cheema *et al.* (1937) reported 40°F to be the best storage temperature for 'Nagpur' mandarin. Karmarkar and Jeshi (1942) also found that this variety of mandarin could be stored for three months at 40°F

without much wastage. According to Cheema and Karmarkar (1942) the *mosambi* orange grown in Bombay State could be kept for four to five months at 40°F.

Khan (1941) working in the Punjab reported 36°-39°F as the optimum storage temperature both for mandarins and sweet oranges. Mandarins from Lyallpur market kept good for five weeks and from Pathankot market for four weeks only. Carefully picked mandarin from the Government Garden, Lyallpur, however, stored well for as long as seven weeks. But the four sweet orange varieties, namely 'Valencia Late', 'Common Malta', 'Seville' and 'Blood Red' remained in good condition for four-and-a-half, four, three and three months respectively. Lal Singh and Hamid (1942) reported 36°-39°F as the best storage temperature for different orange varieties. These findings were corroborated by Bajwa and Kirpal Singh (1945). Storage life of sweet oranges was further shown by Kirpal Singh (1945) to be materially influenced by the kind of root-stock used in their propagation. Malta, common fruit on *Nasnaran* root-stock, a citrus species from Ceylon, had a storage life of 18 weeks as against 14 weeks on sweet lime and citron root-stocks. Likewise, 'Malta Blood Red' fruit on rough lemon stored well for 14 weeks as compared with 11 weeks when propagated on 'Jullunduri Khatti' (smooth lemon).

A small commercial trial was conducted by Ponnappa (1949) on the cold storage of 'Coorg' mandarins grown in southern India. He reported that at 39°-42°F fruit could be kept in saleable condition for two-and-a-half months but 15 per cent wastage was recorded during this period. Srivastava and Mathur (1954) also studied the storage behaviour of 'Coorg' mandarin at 42°-45°F with a relative humidity of 85-90 per cent. Undamaged yellow fruits underwent a wastage of about 15 per cent after 50 days of storage.

Pre-Storage Treatment of Fruit

Before actual storage the fruit may be subjected to various treatments like de-greening, cleaning, hydro-cooling, immersion in hot water, irradiation, waxing, etc., to prolong the fruit life. Some recent work done on these aspects is also reviewed below.

A high incidence of rind breakdown was observed in case of de-greening at 94 per cent R.H. by Hopkins and McCornack (1960, 1961). The fruit treated with lower R.H. decayed much more rapidly. A high percentage of breakdown also occurred in fruit which had been left for two days before processing.

Davis, Harding and Sunday (1963) observed that the amount of rind breakdown in sweet orange varieties increased with increasing length of brushing time from one to five minutes in the process of

washing and cleaning, and also with delay in brushing after harvesting the fruit. 'Pineapple' and 'Muscott Honey' varieties were more subject to rind breakdown than 'Valencias' when held at 70°F and 85 per cent R.H. The softness of the oranges and their position on brushes also influenced rind breakdown.

Grierson and Hayward (1958, 1959) observed that in the hydro-cooled Hamlin oranges both decay and peel injury were higher than in the uncooled oranges. The addition of Dowicide A in the hydro-cooler water decreased decay for 17 days but caused a slight increase in peel injury. However, in 'Pineapple' orange Dowi-cooling caused a peel injury to a serious level. They showed that water wax (Lake Alfred Wax 101 A) can withstand hydro-cooling and can, therefore, be applied before or after hydro-cooling. In 'Valencia' oranges hydro-cooling followed by cool temperatures in transit resulted in good control of decay for up to ten days, though peel injury was slightly increased by hydro-cooling. Dowi-cooling sharply reduced decay but almost doubled peel injury.

Smoot and Melvin (1965) observed that immersion of fruit in hot water at 128°F for 5 minutes effectively reduced post-harvest decay of natural-coloured oranges, but did not reduce decay of 'Hamlin' oranges which required ethylene de-greening treatment and which were harvested early in the season. Hot-water treatment reduced the incidence of decay of oranges and tangerines as much as or more than the fungicide sodium-o-phenyl phenate.

Studying the effect of gamma radiation on the storage life of 'Shamouti' oranges, Bakai-Golan and Kahan (1966) observed that doses of 250 brads prevented any development of rot during the entire storage period of 80 days at 23°C. Stem-end rot occurred frequently in irradiated fruit, possibly owing to an increase in susceptibility following irradiation treatment.

Dennison, Grierson and Ahmed (1966, 1967) also reported that irradiation doses above 100 brads reduced decay in 'Pineapple' and 'Valencia' oranges stored at 70°F for 21 days without Diphenyl pads. Irradiation seemed to induce peel injury but 'Temple' fruits were less susceptible than the fruit of other sweet orange varieties. The severity of peel injury increased with increase in radiation dose and storage temperature and duration. No difference was observed in the colour or consistency of juice from irradiated fruit but the flavour was rated low. In view of severe peel injury they did not recommend irradiation for the preservation of Florida citrus fruits.

According to Guerrero *et al.* (1967), waxed fruits of 'Washington Navel' oranges withstood irradiation damage better than the unwaxed. Doses of 200 brad increased juice pH significantly and decreased the percentage of soluble solids and crushing resistance of pulp.

Hopkins and Loucks (1955) treated the fruit of some sweet orange varieties with a solution of 2 per cent Dowicide A, 1 per cent Hexamine and 0.4 per cent sodium hydroxide and stored both the treated and untreated fruit at 60°F for three weeks. They observed that losses from stem-end rot and blue and green moulds were markedly reduced in treated fruit stored at 60°F. Chace and Harding (1962, 1963) also observed that pre-storage treatment of fruit with wax containing 1 per cent Dowicide A and 0.5 per cent Hexamine reduced decay as compared with simple wax treatment.

In 'Valencia' oranges stored at 42°F, Diphenyl wraps, borax and SOPP all reduced mould wastage but did not give complete control (Tindale, 1959). Grierson (1960) reported that hydro-cooling with the addition of Dowicide A and the use of Diphenyl pads markedly reduced storage and transit losses in Florida citrus packed in polythene bags. Air-cooling and Dow-hex dipping resulted in even lower losses, but at higher cost.

Working on the treatment of 'Valencia' oranges for the prevention of mould decay, Khalifa and Kuykendall (1966) concluded that pre-storage treatment with MCPA reduced decay throughout a 5-month storage period. Treatment with 2,4-D was significantly better than dry brushing plus waxing or washing plus waxing during a four months of storage. At the end of storage, however, fungus infection was similar in oranges treated with 2,4-D or with dry brushing plus waxing or washing plus waxing.

Ben-Yehoshua (1967) studied the effect of various skin coatings on orange fruit. He observed that all the coatings tested improved the appearance of the fruit by imparting a gloss and by reducing drying and shrinkage. In general, Teg (13 per cent) extended the storage life of fruit by about 100 per cent and other coatings by 50 per cent. Teg-coating markedly reduced the rate of weight loss and respiratory activity of the fruit.

Pratella and Tonini (1967) reported that skin coating of fruit of the orange varieties which had previously been inoculated with *Penicillium digitatum* with Decotane (a 2-aminobutane product) 20 per cent a.i. by 10-second dip almost completely prevented the infection of fruit when stored at 22°C for seven days.

Changes in Fruit during Storage

Most of the investigations on the cold storage of oranges were no doubt conducted with economic ends in view and the emphasis was essentially on the control of wastage of fruit, but the physico-chemical aspect of the fruit was also studied by several workers with a view to assess the varietal behaviour in the preservation of fruit quality during storage.

Trout *et al.* (1938) found that at 40°F and about 80 per cent relative humidity the loss of weight per day in oranges from Merbein (Australia) was very nearly 0.1 per cent of the original weight. According to Hamersma (1939), the loss in weight of South African 'Navel' oranges stored from 0 to 12 weeks at 38°F was of no practical value. It was caused by both peel and juice, the latter being somewhat more responsible. Huelin (1942) stated that the loss of weight between picking and marketing should be kept within five to six per cent of the original fresh weight of the fruit. The sweating treatment for the customary seven days in field boxes before packing did not involve a weight loss of more than six per cent. The use of various detergent solutions before packing the fruit accelerated the wilting of oranges, the increase in loss of weight being from 40 to 140 per cent. These effects largely disappeared if the substances were removed by subsequent rinsing.

Regarding sugar content, Trout *et al.* (1938) reported that in 'Washington Navel' orange stored at 40°F the total sugar content of juice increased by 0.05 per cent per week. In their opinion this apparent increase was entirely owing to the loss of fruit weight.

Reduction in the acidity of juice during storage engaged greater attention of researchers as it was considered to be a better criterion of palatability of fruit. The comparison of titrable acidity and acid flavour (taste) gave a correlation coefficient of 0.88, whereas for Brix/Acid ratio and acid flavour (taste) the correlation coefficient was 0.87 (Trout *et al.*, 1938). This indicated that there was no added advantage in the use of Brix/Acid ratio. They also found that fall in acid values of juice from 'Washington Navel' orange stored at 40°F was 0.02 per cent per week. Huelin (1942) observed on the basis of a large number of analyses that 'Washington Navel' orange lost from 2.0 to 2.5 per cent of its initial acidity per week and the 'Valencia Late' 1 per cent. He added that the rate of loss of acidity was practically independent of storage temperatures between 40°F and 50°F.

No loss in Vitamin C content occurred in South African oranges stored for three months at 38°F as reported by Hamersma (1939). The difference between 'Valencias' and 'Navels' in Vitamin C value, and the effect of storage on this value were also significant. Huelin (1942) also observed that 'Navel' orange after several weeks of storage differed little in ascorbic acid content from the original figure of 0.065 per cent.

According to Metlickii and Cehomskaja (1949), high ascorbic acid content of citrus fruits determined their resistance to physiological breakdown during storage. Tindale (1950) reporting on scion/stock relationships observed that 'Navel' orange on Citronelle (rough

lemon) stock showed more wastage from *Penicillium* moulds than 'Navel' orange grown from trees on other stocks during cold storage. He further recorded that during storage the ascorbic acid content of 'Valencia' fruits from trees on Citronelle stock decreased much more than in fruits from trees on other stocks. Possibly in this case also the greater wastage of fruit was associated with rapid decline in the ascorbic acid content.

The rate and extent of colour development in oranges during storage has also been recorded. Hall (1938) observed that at 50°F early picked fruit would develop a good orange colour and improve in palatability whereas such changes would not occur at 36°F and were very slow at 40°F. Huelin (1942) found that 'Navel' orange picked towards the end of May and stored at 45° to 50°F continued to colour as well as on the tree and ultimately attained a full orange colour. At 40°F these changes were much less complete. Colouring at 37°F was inappreciable.

Reig and Albert (1966) found that during storage the quality of orange juice greatly deteriorated after six weeks and mould incidence was higher after eight weeks. Weight loss during storage was positively related to the level of nitrogen application and storage temperature. The juice content decreased in all cases, the loss being lowest with medium nitrogen application and greatest at highest storage temperature. Nitrogen level was related positively to soluble solids content, acidity and initial reducing sugars content, but negatively to Vitamin C content. Reducing sugars increased in quantity during storage specially between the 36th and 40th day. Vitamin C losses were least at low temperature and in fruit grown without N application. The period of most rapid loss was 30-40 days after storage.

Production Variables in Relation to Storage Life. Apart from the storage factors reviewed above, several production variables also exert a profound effect on the wastage and storage life of fruit. The influence of fruit maturity at the time of picking on the subsequent storage behaviour of fruit is the most thoroughly investigated field.

Stahl and Camp (1936) studied the effects of various temperatures and stages of maturity on the keeping quality of 'Florida' oranges and found that at any of the storage temperatures the loss of weight during storage progressed with the degree of maturity at the picking and storing times. Tomkins (1937) observed that early picked 'Palestine' oranges were more susceptible to mould rotting than the late-picked fruit. Similar observations were made by Furlong and Barker (1939) who stated that late season fruit was more resistant to low temperature and skin injuries than the early season fruit.

Hall (1938) reviewing the handling and storage of Australian citrus fruits in relation to wastage remarked that early picked fruit which was resistant to fungal attack should be stored at higher temperature to avoid storage spot and improve palatability. The late-picked fruit which was less susceptible to storage spot should be stored at a lower temperature to reduce fungal wastage and maintain palatability.

Trout *et al.* (1938) found that 'Washington Navel' orange, picked in early June, remained palatable for 12 weeks at 40°-42°F and for a further week at atmospheric temperatures. If the fruit was left on the tree and picked later, its life in cold storage was reduced by an equivalent period. Huelin (1942) also recorded that 'Navels' picked in mid May, mid June and mid July had a storage life of 12, 10 and 7 weeks respectively at 45°F. For 'Valencias' picked in the months of September and December the corresponding storage life was 12 and 9 weeks.

Inove and Koto (1953) harvested 'Satsuma' oranges on 20th and 30th November and 10th December and stored them up to 19th April. They found that spoilage losses were 37, 17 and 20 per cent respectively. Fruit colour and calyx condition were the best in the second lot. Tindale and Pegg (1955) studied the storage behaviour of 'Washington Navel' orange and concluded that maximum storage life, judged by flavour, was three months when picked in late June, two-and-a-half months when picked in late August. The incidence of low temperature disorders was the greatest in early picked fruit and appeared within six weeks.

Chace and Harding (1962, 1963) observed that fruits picked with a solids: acid ratio of 18:5:1 or 17:5:1 retained its quality well during storage but in case of fruit picked with a solids:acid ratio of 23:4:1 off-flavours developed during storage.

'Pope's Summer Orange' picked in April developed less decay during storage and subsequent holding than the fruit picked in May (Chace and Harding, 1962). Similarly March-harvested 'Valencia' orange fruits stored better at 48°F than at 38°F, but June-harvested fruit stored better at 38°F (Khalifa and Kuykendall, 1965).

Besides fruit maturity, the age of the tree was also found to be related with storage life. Williams (1938) held that oranges from young trees did not keep nearly so well nor so long as those from the older trees.

Even the method of picking is known to determine the storage life of citrus fruits to some extent. Investigations by Winston (1936) indicated that pulling was not only cheaper than clipping but was advantageous in controlling stem-end rots, provided there was no

tearing injuries to the fruit. Earlier, De Leon (1928) had also recorded the advantages of pulling over clipping in 'Philippine' mandarin oranges where stem-end rot was an important problem. Hall (1938) recommended that oranges and lemons should be clipped from the trees with special clippers whereas mandarins may be pulled and grapefruit either pulled or clipped. Huelin (1942) found that clipping definitely decreased rotting in four out of five experiments on oranges. In the experiment with mandarins clipping resulted in a slight increase in rotting. However, Hopkins and McCornack (1961) did not find any significant difference in total decay between the pulled and clipped fruits in regard to rind breakdown or decay.

Regarding the role of cultural conditions on the storage behaviour of citrus fruits, Huelin (1942) observed that under heavy irrigation the incidence of storage spot was not affected but the rots were generally increased. Wastage in stored 'Griffith' orange was generally increased by green manuring with tickbeans or lucerne. He assumed that the effect of the green-manured crop was mainly owing to nitrogen added to the soil. However, the application of nitrogen as ammonium sulphate to 'Navel' orange trees had practically no effect on the subsequent keeping quality of the fruit. He summarised that a liberal supply of moisture and nitrogen promoted abundant tree growth with high fruit yields but produced fruit of somewhat poor keeping quality with comparatively coarse rind and juice low in soluble solids and acid. Bordeaux sprays reduced storage spot and rotting but were liable to cause injury when applied late in the season.

Harding *et al.* (1958) observed that in storage tests, fertilization with N and K had less influence on the incidence of pitting or decay on fruit maturity than conditions during storage and marketing.

De Fossard (1959) observed that orange fruit developing under conditions of drought was less susceptible to peel breakdown due to brown stem diseases than that developing under better moisture conditions. Other cultural conditions appeared to have little effect on the occurrence of this disease.

Khalifa and Kuykendall (1965) found that 'Valencia' orange fruit collected from the Sal River Valley (sandy loam soil, mean annual temperature 69.4°F) did not suffer any change in soluble solids during storage but that collected from Yuma (sandy soil, mean annual temperature 72.5°F) showed decline in soluble solids.

The dominating effect of the other complex production variables on the keeping quality of citrus fruits has also been stressed by Huelin (1942). Oranges from the dry inland irrigated areas with an annual rainfall of only 25 to 38 cm were generally of high quality and the problem of controlling rots and rind disorders was relatively less

acute. Storage problems were, however, more complex in oranges grown in the wet coastal districts of New South Wales with a rainfall of 76 to 114 cm. With the higher rainfall was associated a greater liability to rots and storage spots.

Kirpal Singh (1945) and Tindale (1950) recorded market effect of some citrus root-stocks on the keeping-quality of oranges and grapefruit. Sykes (1947) stated that factors affecting the resistance of fruit to fungal infection included variety, locality, soil, rainfall and manurial treatment. Klotz (1951) held that the keeping-quality of citrus fruits was influenced by variety, root-stock, nutrition and water availability. Metlickii (1954) observed that for prolonged storage only fruit of optimum physiological maturity was suitable and success was affected by external conditions of growth such as the place of origin. The percentage spoilage in mandarins grown at Ahalseni, Adzar (USSR) after four months' storage was three times higher than in those grown at Suhumi, Abbaz (USSR).

The diversity of conditions of production and the attendant storage problems of citrus fruits have been eloquently stated by Wardlaw (1937).

"Although the genus *Citrus* is primarily of tropical origin, the largest-producing areas actually lie outside the tropics. Citrus fruits are thus grown under a wide range of cultural conditions in all five continents, from moist tropical regions of uniformly high temperature to subtropical and warm temperate regions where trees may occasionally suffer from frost injury. Since environment influences not only the growth of the plant but also the physiological behaviour of fruit after it has been harvested, diversity rather than uniformity characterises the storage requirements of citrus produced in different countries."

The idea of diversity has been finely extended by Hall (1938) in the light of his experience on the storage of Australian citrus fruits:

"In experiments on the storage of Australian citrus fruit a similar diversity in storage behaviour has been found not only between inland irrigated and coastal areas which are radically different in climate, but also between different orchards in the one locality. This variability extends even to different trees in the same orchard and to individual fruits on the one tree."

Kidd (1930) has, therefore, rightly stressed the phenomenon of 'variety on all hands' in these words:

"There is the variety in kinds of fruits; there is the great variety in conditions of production, in locality, soil, climate and season; there is the variety in markets and in marketing organisations, and the variety in transport and storage conditions."

In view of this 'variety' which in turn influences the quality and the storage properties of fruit the main problem of the industry is to increase and systematise our knowledge of the relation between production variables and storage behaviour on the keeping quality of fruit. Since the knowledge of principles in these matters does not suffice the industry, Kidd (1930) urged a considerable extension of local testing of storage quality. He stated, "Every fruit production area of any importance, which does not pass the whole of its produce into immediate local consumption, should be equipped with an experimental or trial storage."

The investigations reported in the following pages were undertaken by the author to fulfil this need of the citrus industry in India.

III. FRUIT MATERIAL, EQUIPMENT AND EXPERIMENTAL PLAN

FRUIT MATERIAL

(a) **Mandarin Orange** (*Citrus reticulata* **Blanco**)

Two commercial types of mandarin oranges, viz. 'Coorg' orange and 'Nagpur' orange (santra) were investigated. These types are grown in separate zones under altogether different conditions of soil and climate. A brief historic review of the introduction of these varieties, their cropping behaviour and description of their fruit characters is given below:

(i) '*Coorg*' mandarin orange. According to the official Gazetteer of Mysore and Coorg, the orange trees were popularly grown in the gardens of Rajas who ruled Coorg for two centuries till 1834, when this State was annexed to British India. The commercial plantations are, however, of recent origin and are closely associated with the establishment of coffee estates by the British settlers. Most of the orange plantations are inter-planted with coffee along the hill slopes all over Coorg at an average altitude of 915 m. The annual rainfall is about 152 cm (more than 254 cm at places) and is well distributed from April to December. The minimum and the maximum temperatures experienced are 48°F and 90°F and the relative humidity from moderate to high. The soils are black or red loamy and mostly well-drained. Soils that are very rich in lime are known to be toxic and harmful to mandarin cultivation (Sham Singh and Daljit Singh, 1957a).

It is estimated that nearly 22,000 acres are under mandarin oranges in Coorg and the average yield is about 5 to 6 tons per acre. The number of trees per acre varies from 134 to 200 depending upon the fertility of soil.

The tree is usually raised from seed. It is large, columnar in shape, sparingly spinous with compact foliage and heavy bearing. There are two cropping seasons in a year. Some trees bear fruit during one season whereas the remaining in the other. The main crop is harvested during January-February and constitutes 90 per cent of the annual production. The fruit of the main season crop develops an attractive orange colour, sweet taste and excellent flavour for which it enjoys high reputation all over the South Indian markets. The second or the rainy-season crop (July-August) produces green fruit with acid taste and poor keeping-quality.

The fruit of the main season crop (Fig. 2) is oblate to globose with uniform attractive orange colour, finely papillate and finely wrinkled, glossy, stalk-end necked or depressed with glandular ribs extending through the collars; rind thin to medium, soft, adherence slight; seg-

ments 8 to 12; pulp vesicles uniformly sunken, texture fine and tender; flavour excellent; juice abundant, deep chrome, sweetness and acidity well blended when fully ripe; rag little, seeds 16 to 27 per fruit, medium in size and green when cut.



Fig. 2. (Top) 'Sathgudi' orange (*C. sinensis* Osbeck); (Bottom) 'Coorg' mandarin (*C. reticulata* Blanco). Note the tight adherence of peel to the pulp in 'Sathgudi' orange and loose attachment in 'Coorg' mandarin. A large central cavity, characteristic of the mandarin orange, is quite conspicuous.

The 'Coorg' mandarin orange bears a striking resemblance to the 'Desi' mandarin orange grown in the Punjab, although these two varieties are produced under distinctly different climatic regions of India (Fig. 1). The 'Desi' orange (*santra*) is grown in the submontane districts of the Punjab up to an altitude of 609 m with 152 cm of annual rain which is restricted from June to September. It is also grown in the Punjab plains extending west, but the performance of the tree under these conditions is erratic and the quality of fruit poor. Because of low winter temperatures the fruit develops deep orange colour, becomes puffy and loose-skinned, and does not acquire the sweetness and flavour characteristic of other mandarins.

(ii) '*Nagpur*' mandarin orange (*santra*). It is said that this orange was first introduced into Nagpur by the Bhonsala Raja Raghuji II about the end of the eighteenth century. It is regarded as the world's finest type of mandarin orange. The climate and soil around Nagpur in central India are ideally suitable for the production of this fruit. It is grown at an elevation of about 365 m with an average annual rainfall of 111 cm and relative humidity 53 per cent. The maximum and the minimum temperatures are 117°F and 43°F respectively. The mandarin groves are mostly established under artificial irrigation conditions on heavy, black soils under-laid with *murrum* which provides good drainage (Gandhi, 1956).

The tree is usually large, moderately spreading with compact foliage, frequently spineless and a prolific bearer. Like the 'Coorg' orange, this variety also blossoms twice a year in the Nagpur region. The blossoming of June-July is called 'mrigh bahar'. The resulting crop begins to ripen in February but harvesting continues till the end of April. The second flowering occurs in December-January and is known as 'ambia bahar'. The fruit of this flowering is ready in September and is harvested by the end of November. About 70 per cent of the annual production of 'Nagpur' orange is derived from the 'mrigh bahar' which forms the main season crop and the remaining 30 per cent from the 'ambia bahar', the second season.

The fruit of the main season crop is sub-globose; colour not uniform, generally cadmium; surface smooth, glossy; stalk-end even or drawn-out and warty with glandular furrows; rind thin, firmness soft, adherence slight; segments 9 to 12; pulp vesicles uniformly marigold; texture fine and tender; flavour excellent; juice abundant, saffron yellow, sweetness and acidity well blended; rag little; seeds 15 to 23 per fruit, medium-sized, light green when cut.

The fruit of the second season crop is poor in quality just like the second season crop of 'Coorg' oranges but not to the same extent.

The 'Nagpur' mandarin orange may be compared with a similar variety named 'Burnihat' or 'Khasi' mandarin orange grown in Assam (Bhattacharya and Dutta, 1949). The latter variety is cultivated under more humid and hot climate and, therefore, produces less compact fruit with slight or no adherence of rind to the segments. The quality of juice and the texture of pulp are, however, excellent.

(b) **Sweet Orange** (*Citrus sinensis* Osbeck)

'Sathgudi' was the only variety of tight-skinned sweet orange under study. It is extensively grown in Andhra State and commands good reputation in the south Indian markets (Hayes, 1953). The fruit of this variety is very sweet and worthy of its name 'sath' means true and

'gud' means sweet—thus the name 'Sathgudi' implies a 'truly sweet' fruit.

The tree is raised by bud grafting on rough lemon root-stock. It is large, spreading and spineless with dark dense foliage and heavy bearing (Fig. 3).



Fig. 3. Sweet orange tree showing its spreading habit, dense foliage and heavy bearing

The fruit of 'Sathgudi' (Fig. 2) is medium-sized, sub-globose, the height being a little more than the diameter; rind medium thick, tight, semi-glossy, smooth and finely pitted; empire yellow, aureole and navel absent; pulp uniformly straw-coloured, juicy, tender; flavour good; segments 10 to 12 and the number of mature seeds per fruit 12 to 20 (Sham Singh and Daljit Singh, 1957b).

SOURCE AND HANDLING OF FRUIT

The 'Coorg' mandarin orange was picked under direct supervision, though it was obtained through the Coorg Orange Growers' Co-operative Society, Pollibetta. For studying the optimum storage temperature, the fruit of the main crop was picked during the last week of January, 1951 and that of the rainy season crop during the first week of August, 1951. To determine the effect of orchard variability on the storage life of fruit, the produce of several orchards situated in different parts of 'Coorg' was collected during the middle of February, 1952. The harvesting season was late that year owing to late blossoming.

For comparing the different methods of picking and the different sizes of fruit in relation to storage life, fruit was picked also during the middle of February, 1952. In either case, fruit crop of a single tree was utilized in order to reduce the experimental error to the minimum.

The fruit of the 'Nagpur' mandarin orange was obtained through the Central Hindusthan Orange and Cold Storage Company Limited, Nagpur. The fruit of the main crop was picked during the third week of March, 1952, which usually represents the peak period for Nagpur orange, and that of the rainy season crop during the second week of October, 1952.

The 'Sathgudi', Sweet Orange fruit was obtained from Kodur (Andhra State) through the Kodur Fruit Growers' Co-operative Society. Fruit meant for investigating the optimum storage temperature was picked during the first week of December, 1951, and that for studying the change in colour was also picked at the same time during 1951 and 1952.

Every precaution was taken to ensure proper packing and handling of the experimental fruit material. Only sound fruits of proper colour, size and shape, characteristic of the variety were retained and all the malformed, sunburnt and cankered fruits were rejected. The selected fruits were packed carefully in wooden crates immediately after picking and brought to the laboratory at Mysore.

The 'Coorg' mandarin oranges were transported over a distance of about 60 miles by road in motor trucks. The Nagpur fruit was carried over about 800 miles by rail in three days. Similarly the 'Sathgudi' fruit was brought by rail over a distance of nearly 400 miles in two days. It took another day in the laboratory at Mysore to open and

re-examine the fruit to reject the damaged material and to divide and place the experimental lots in their proper storage chambers. For storing, the fruit was packed in tiers in well-aerated wooden crates. The tops of the crates were left uncovered.

COLD STORAGE CHAMBERS

The cold-storage chambers employed in these investigations were installed during 1950 in the Refrigeration Section, Division of Storage and Preservation, Central Food Technological Research Institute, Mysore. There were four reach-in experimental cold-storage chambers, each with a capacity of about 4.24 cubic metres installed in a series with a common air-lock room. In addition to these chambers there was another set of two walk-in cold-storage rooms each with a capacity of about 28.3 cubic metres with a common air-lock room. Thus, there were eight rooms with different storage temperature ranges for carrying out research on cold-storage of fruits and vegetables.

The relative humidity in cold-storage chambers 1 to 4 and room Nos. 6 and 7, i.e., where storage temperatures were automatically controlled by mechanical devices, ranged from 85 to 90 per cent. The relative humidity in the air-lock room Nos. 5 and 8 was 70 to 75 per cent and 75 to 80 per cent respectively.

The refrigerant used was di-chloro-di-fluoro-methane, commercially known as Freon or F-12. It is a non-inflammable, odourless and non-poisonous gas with the advantage over the other refrigerants that it will not spoil the stored commodity even if it leaks into storage chamber. It is, therefore, safe to be employed in cold storages meant for perishable foods particularly fruits and vegetables.

For convenience in the conduct of experimental work, each of the four cold-storage chambers was further divided into four compartments. Each compartment was provided with adjustable shelves to place the wooden crates packed with fruit. The two cold-storage rooms were also provided with suitable racks to accommodate conveniently the experimental material. Every cold-storage chamber and the cold-storage room was also provided with necessary floor dunnage made up of thick wooden battens for ventilation.

To collect reliable data in regard to the physical conditions prevailing during investigation, every experimental chamber room was provided with a maximum and minimum thermometer, a wet and dry bulb thermometer, a thermograph and hygrometer. Necessary data in regard to the prevailing storage temperature and the relative humidity were daily recorded in the log book maintained for this purpose.

EXPERIMENTAL PLAN

As these investigations were undertaken to determine the optimum cold-storage temperatures for different types of oranges produced and

picked under varying conditions, each problem was defined at the outset and treated as a self-contained study to find answers to specific questions. The different experiments and the treatments included under each are briefly outlined below:

Optimum Storage Temperature for 'Coorg' Orange

Treatments. (a) Storage temperatures: (i) 35°-38°F, (ii) 39°-42°F, (iii) 42°-45°F, (iv) 47°-50°F. The fifth lot was stored at room temperature as a check. (b) Crop seasons: (i) Main season, and (ii) Rainy season. Two hundred fruits constituted each treatment lot. Thus for the five storage conditions, 1,000 fruits were utilized in each crop season.

Effect of Fruit Size on the Keeping-Quality of 'Coorg' Orange

Treatments. (a) Fruit sizes: (i) Large A, (ii) Medium B, (iii) Small C. (b) Crop seasons: (i) Main season, and (ii) Rainy season. The fruit was stored only at the optimum temperature (39°-42°F) determined earlier in the course of these investigations. Since two hundred fruits made up an experimental lot, 600 fruits were used in each cropping season for this experiment.

Effect of Method of Picking on the Cold-Storage Life of 'Coorg' Orange

Treatments. (a) Method of picking: (i) Fruit clipped with clipping scissors, (ii) Fruit pulled off by hand. (b) Storage temperatures: (i) 35°-38°F, (ii) 39°-42°F, and (iii) 42°-45°F. The fruits clipped with the clipping scissors carried the stem-end button along with a very small portion of stem-end piece. The fruits pulled off by hand had no such extra end-piece. At the rate of 200 fruits per lot 1,200 fruits were used in all.

Effect of Orchard Variability on the Cold-Storage Behaviour of 'Coorg' Orange

To evaluate the differential behaviour of the produce of different orchards in cold storage, 200 fruits from each of the eight different orchards located in different parts of Coorg were experimented upon. Only the optimum cold storage temperature, viz. 39°-42°F was used in this trial. The orchards under study were: (1) Balmany Estate, (2) B. & C. Estate, (3) Bhadrakola Estate, (4) Craigmore Estate, (5) Muscabora Estate, (6) Yemmigoondi Estate, (7) Chinnali Estate, (8) Huntsey Estate.

Economics of Cold-Storage Practice in 'Coorg' Mandarin Orange

For carrying out a semi-commercial trial on the cold storage of Coorg orange, 50 crates of fruit of the main season crop were stored at

the optimum temperature range of 39°-42°F. Each crate contained 240 fruits. A total of 12,000 fruits was used in this trial. The fruit was disposed of in the Mysore and Bangalore markets. All details of expenditure and income were maintained to work out the economics of cold-storage practices.

'Nagpur' Mandarin Orange

Optimum Storage Temperature for 'Nagpur' Orange. It was planned on the same lines as Experiment 1 on 'Coorg' orange.

'Sathgudi' Sweet Orange

Optimum Storage Temperature for 'Sathgudi' Orange. In this experiment, lots of 200 fruits each were placed at four cold-storage temperatures, viz. 35°-39°F, 39°-42°F, 42°-45°F and 47°-50°F.

Effect of Fruit Size on the Keeping-quality of 'Sathgudi' Sweet Orange

Treatments. (a) Fruit sizes: (i) Medium 7 cm diameter, and (ii) Large 7.5 cm diameter. (b) Storage temperatures: (i) 39°-42°F, and (ii) 42°-45°F. For the four treatment combinations, 800 fruits were employed in all at the rate of 200 fruits per lot.

Effect of Storage Temperature on Colour Development of 'Sathgudi' Sweet Orange

For this experiment, lots of 200 fruits each were placed at four cold-storage temperatures, viz. 39°-42°F, 42°-45°F, 47°-50°F and 52°-55°F.

Optimum Temperature Combination for Storage and Colour Development of 'Sathgudi' Sweet Orange

As the temperature range of 42°-45°F was found to be the optimum for storage and the temperature range of 52°-55°F was most conducive to colour development, combinations of these two temperature conditions were tried during the following year as under:

Temperature combination	Initial temperature		Succeeding temperature	
	Range	Duration	Range	Duration
A	42°-45°F	14 weeks	52°-55°F	6 weeks
B	52°-55°F	4 weeks	42°-45°F	16 weeks

In this experiment 400 fruits were used in all for the two temperature combination treatments.

Fruit Sampling for Observations

Each experimental lot comprising 200 fruits was further divided into two sub-lots of 100 fruits each and stored separately in wooden crates having the necessary slit openings to allow effective cooling and ventilation. One sub-lot of 100 fruits was kept for studying the wastage whereas the second sub-lot of 100 fruits in the other crate was used for drawing experimental lots for conducting the physico-chemical analyses at fortnightly intervals. Fruits meant for studying the periodic loss in weight during storage were also numbered individually and kept in the second sub-lot.

Data Collected

The orange, like any other fruit, is a living matter even after it is detached from the tree and is capable of carrying out certain life processes which include respiration—a chemical process of breaking down the organic food substances with the liberation of carbon dioxide, and transpiration—the evaporation of water from the skin. The combined effect of these two continuous processes occurring during storage is reflected in gradual loss of fruit weight. Certain other changes in the chemical composition of fruit also continue culminating in its breakdown. To assess the quality of fruit as affected by this natural drift of senescence during storage, regular physico-chemical determinations were made at fortnightly intervals. In the case of fruit kept at room temperature these observations were made at weekly intervals but for the sake of comparison their fortnightly data only have been presented.

Physico-chemical Changes

Loss in weight. For determining the loss in weight of fruit during storage, six fruits in each experimental lot were numbered and weighed individually at fortnightly intervals. The loss in weight was expressed as percentage of the original fresh weight of the fruit.

Peel content. A random sample of three fruits from each experimental lot was used on each occasion. In mandarin oranges, the peel was removed by hand and weighed. The peel of 'Sathgudi' orange was obtained by cutting the fruit into halves, extracting the juice with an electrically driven cone and then separating the rag within. The peel fraction was expressed as percentage of the fresh weight of fruit sample used each time.

Juice content. The segments of mandarin orange and the pulp of 'Sathgudi' orange obtained after removing the peel as described above were further pressed and strained through muslin cloth to remove seeds

and particles of rag. The strained juice in each case was then weighed and expressed as percentage of fresh weight of fruit sample used.

Total soluble solids. The percentage of total soluble solids (mainly sugars) was determined with the help of a portable hand refractometer. The sample of juice for this purpose was taken from the strained juice. The observed values of total soluble solids were then corrected for 68°F.

Titrateable acidity of juice. The percentage of acidity was determined in terms of anhydrous citric acid by titrating the juice against N/10 NaOH, using Phenolphthalein as indicator. Every time 10 ml sample of fresh strained juice was employed after diluting it with a sufficient quantity of distilled water. The appearance of pink colour indicated the end point of titration.

Moisture content of juice. This fraction was determined by drying 10 ml of fresh strained juice in an electric oven at 68°-70°C to constant weight.

Reducing sugars. Reducing sugars were determined by Lane and Eynon (1923) Method using the fresh, strained and neutralised juice.

Ascorbic acid. For this determination 5 ml of aliquots of juice were taken. An equal volume of 2 per cent metaphosphoric acid was added and the mixture titrated against the standardised solution of 2, 6-dichlorophenolindophenol dye. The dye was previously standardised against the solution of pure ascorbic acid (T. Merck) prepared in 2 per cent metaphosphoric acid.

Colour development. The colour grade developed by the flavour of 'Sathgudi' orange at different storage temperatures was judged by comparing it with the Horticultural Colour Chart of Wilson (1938). Quantitative values of colour constituents were determined with the aid of B.D.H. Lovibond Tintometer.

Storage Life of Fruit

Wastage of fruit from various causes during storage is a common phenomenon and it is the extent of this wastage that determines the storage life of a particular kind of fruit. Keeping in view the economic aspect of cold storage, the wastage percentage should not exceed a certain limit. The arbitrary limit fixed at 10 per cent by various researchers was used in determining the storage life of fruits during the present investigations.

Post-storage Behaviour of Fruit

The ultimate success of cold storage practice lies in the fact that the stored fruit should be able to withstand the ordinary atmospheric temperatures for a few days so that it could be profitably disposed of

after cold storage. For this purpose, samples of 'Sathgudi' oranges were taken at the end of the storage period and kept for seven days at room temperature to study the change in taste and flavour. Data on loss of fruit weight and changes in the important constituents of juice were also collected.

Storage Disorders and Mould Wastage

An account was kept of the storage disorders and mould wastage during storage for each kind of fruit. Effort was made to identify the causes and the extent of such wastage.

IV. OPTIMUM STORAGE TEMPERATURE FOR 'COORG' AND 'NAGPUR' MANDARINS AND 'SATHGUDI' SWEET ORANGE

LOSS IN WEIGHT

'Coorg' Mandarin Orange

Main-season crop. 'Coorg' mandarin orange continued to lose weight progressively throughout the storage period under all the temperatures (Table 1). Of course, the percentage loss in weight was the least at the lowest storage temperature range of 35°-38°F. At the end of 14 weeks' storage, the cumulative loss in weight varied from 10.3 to 18.7 per cent for the storage temperatures employed. It is interesting to note, however, that the differential effects of storage temperatures became visible at the end of the very first fortnight. This is evidenced by the progressive increase in the loss of fruit weight from 1.3 per cent to 2.4 per cent with the rise in storage temperatures. The initial differences in weight loss were only magnified with the passage of time in storage.

Table 1. LOSS IN THE WEIGHT OF 'COORG' MANDARIN ORANGE (CUMULATIVE LOSS %) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Original fresh wt per fruit (g)	Storage period in weeks						
		2	4	6	8	10	12	14
Main-season crop								
35°-38°F	154.5	1.3	2.7	3.7	4.7	6.7	8.9	10.3
39°-42°F	153.0	1.5	3.4	5.2	7.7	9.3	11.7	13.9
42°-45°F	149.6	2.1	3.5	6.8	9.4	11.9	14.1	16.5
47°-50°F	149.4	2.4	4.8	7.4	9.8	12.9	15.0	18.7
Mean	151.6	1.8	3.6	5.8	7.9	10.2	12.4	14.9
Rainy-season crop								
35°-38°F	161.0	3.8	7.4	11.7	15.9	19.8	—	—
39°-42°F	156.8	4.0	7.7	11.9	16.6	20.7	—	—
42°-45°F	146.8	4.2	8.5	13.1	17.2	21.2	—	—
47°-50°F	166.4	4.3	9.2	13.5	17.9	22.3	—	—
Mean	157.7	4.1	8.2	12.6	16.9	21.0	—	—

To determine whether the loss in weight of fruit occurred at a uniform rate throughout the storage period or it differed at various stages, the fortnightly rates of loss were calculated and subjected to analysis of variance. The results showed that as the storage period increased there was a corresponding rise in the rate of fortnightly loss as well. The average fortnightly loss in fruit weight actually ranged from 1.8 per cent in the first fortnight to 2.4 per cent in the seventh fortnight. This suggests that the loss in weight of fruit is not a simple phenomenon of moisture loss over a given stretch of storage period as is usually understood. In fact, other physico-chemical changes are concurrently taking place in the fruit which gradually lower its resistance to the loss of moisture. Respiration, no doubt, accounts for some loss in weight of fruit during storage but since water loss constitutes the major part of the gross loss in weight, emphasis has necessarily to be on moisture variations of fruit.

Rainy-season crop. The cumulative loss in the weight of 'Coorg' orange of the rainy-season crop bore a direct relationship with the storage temperature employed (Table 1). At 35°-38°F, after 10 weeks' storage, the reduction in weight amounted to 19.8 per cent of the original fresh weight. The loss went up to 22.3 per cent at the highest temperatures of 47°-50°F during this period. Relative effects of different temperatures were noticeable at the end of the first fortnight and persisted throughout the storage period.

The time trend in cumulative loss of weight was also well-marked. Losses were progressively higher depending upon the length of storage period. From an initial average loss of 4.1 per cent in the first fortnight it ultimately amounted to 21.0 per cent in ten weeks.

This loss when expressed as actual reduction during individual fortnightly periods revealed that from a mean fortnightly loss of 3.96 per cent at 35°-38°F it rose to 4.46 per cent at 47°-50°F. The rate of loss was, however, not affected by duration of storage.

'Nagpur' Mandarin Orange

Main-season crop. The storage temperature greatly influenced the rate of weight loss and the individual temperature effects were noticeable even after two weeks of storage (Table 2). From 0.9 per cent loss in weight occurring under the lowest temperature range of 35°-38°F, it became almost double at 47°-50°F. The losses continued to increase progressively under all storage temperatures with the prolongation of storage period so much so that at the end of 14 weeks the values ranged from 9.9 to 16.3 per cent. It is noteworthy that between temperature ranges of 42°-45°F and 47°-50°F the losses in fruit weight were nearly of the same order during the first six weeks, and thereafter

higher storage temperature of 47°-50°F begins to show up the higher rate of loss in fruit weight.

The study of the fortnightly rate of loss in fruit weight also confirmed the above observations. This increased both with rise in storage temperature and storage duration. The average fortnightly loss was only 1.41 per cent at 35°-38°F as compared with 2.33 per cent at 47°-50°F. Similarly, from the initial rate of 1.38 per cent in the first fortnight the average loss mounted to 2.28 per cent in the last fortnight.

Rainy-season crop. The progressive losses in the weight of 'Nagpur' orange of the rainy-season crop were nearly of the same order under the three lower storage temperatures (Table 2). In absolute values the loss ranged from 13.1 to 14.2 per cent after ten weeks' storage showing a negligible increase in weight loss with rise in storage temperature. But the highest storage temperature of 47°-50°F caused significantly higher losses than these, recording an aggregate loss of 18.5 per cent during the same period.

Table 2. LOSS IN THE WEIGHT OF 'NAGPUR' MANDARIN ORANGE (CUMULATIVE LOSS %) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Original fresh wt per fruit (g)	Storage period in weeks						
		2	4	6	8	10	12	14
Main-season crop								
35°-38°F	140.5	0.9	1.9	3.2	4.2	6.0	7.6	9.9
39°-42°F	134.5	1.3	2.8	4.6	5.8	7.6	9.6	11.5
42°-45°F	138.3	1.6	3.2	5.7	7.1	9.6	11.7	13.8
47°-50°F	135.3	1.7	3.2	5.8	8.6	10.9	13.5	16.3
Mean	137.1	1.4	2.8	4.8	6.4	8.5	10.6	12.9
Rainy-season crop								
35°-38°F	140.3	1.9	4.9	7.3	9.9	13.1	—	—
39°-42°F	135.5	2.2	5.0	7.6	10.8	13.6	—	—
42°-45°F	140.1	2.4	5.1	8.2	19.9	14.2	—	—
47°-50°F	145.4	2.9	6.8	10.9	13.8	18.5	—	—
Mean	140.3	2.35	5.45	8.50	11.35	14.85	—	—

The effect of storage duration on weight loss was more prominent. Averaged over all the storage temperatures employed, a mean loss of 2.35 per cent was recorded at the end of the first fortnight which progressively increased to 14.85 per cent after ten weeks.

Table 3. LOSS IN THE WEIGHT OF 'SATHGUDI' SWEET ORANGE (CUMULATIVE LOSS %) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage	Original fresh wt per fruit (g)	Storage period in weeks									
		2	4	6	8	10	12	14	16	18	20
35°-38°F	189.7	2.1	3.8	5.9	8.1	9.9	12.0	14.2	16.4	18.0	21.3
39°-42°F	193.2	2.1	3.9	6.1	8.5	10.9	13.1	15.6	17.8	20.9	23.1
42°-45°F	198.0	2.3	4.1	6.3	8.7	11.4	13.2	15.8	17.9	21.2	23.8
47°-50°F	187.3	2.5	4.5	7.1	9.7	12.5	14.6	17.9	20.7	23.4	26.5
Mean	192.2	2.25	4.07	6.35	8.75	11.17	13.22	15.87	18.20	21.12	23.67

The assessment of the actual loss in fruit weight during individual fortnights revealed similar effects.

'Sathgudi' Sweet Orange

The effect of storage temperature on gross loss in the weight of 'Sathgudi' orange became visible just after two weeks of storage (Table 3). Progressively greater loss was noted at relatively higher storage temperatures. These initial trends persisted throughout and the final values of cumulative loss after 20 weeks' storage manifested more distinctly the relative effects of individual storage temperatures. From the lowest value of 21.3 per cent at 35°-38°F the loss progressively increased to 26.5 per cent at 47°-50°F. The intermediate temperature ranges of 39°-42°F and 42°-45°F were intermediate in effect and behaved almost alike.

The effect of storage duration on cumulative loss in weight was also additive and progressive. Except for minor fluctuations the mean fortnightly loss continued to increase from the initial value of 2.25 per cent to 2.92 per cent during 18 weeks' storage.

Table 4. PEEL CONTENT OF 'COORG' MANDARIN ORANGE (PEEL PERCENTAGE) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks									Mean C.D.
	0	2	4	6	8	10	12	14		
Main-season crop										± 0.83
35°-38°F	31.2	31.9	31.9	33.9	34.1	31.3	33.6	33.2	32.75	
39°-42°F	31.2	33.1	34.1	34.4	33.9	34.4	34.3	33.8	33.6	
42°-45°F	31.2	33.3	34.7	35.4	34.7	34.3	35.0	33.3	34.0	
47°-50°F	31.2	36.0	34.5	36.7	34.8	35.3	35.4	35.0	34.8	
Mean C.D. ± 1.18	31.2	33.6	33.8	35.1	34.4	33.8	34.6	33.8	—	
Rainy-season crop										± 1.54
35°-38°F	28.9	29.6	29.7	27.6	27.6	27.1	—	—	28.4	
39°-42°F	28.9	31.7	31.2	28.7	31.8	27.9	—	—	30.0	
42°-45°F	28.9	29.2	30.1	32.2	31.4	30.1	—	—	30.3	
47°-50°F	28.8	33.7	34.1	31.5	32.2	34.4	—	—	32.5	
Mean C.D. ± 1.89	28.99	31.1	31.3	30.0	30.8	29.9	—	—	—	

'Coorg' Mandarin Orange

Main-season crop. The effect of storage temperature on peel content was well marked in as much as the mean peel percentage of fruit kept at 35°-38°F was 32.5 as against 34.8 at 47°-50°F (Table 4). The results showed that as the storage temperature increased the peel percentage also attained higher value.

The fruit at the commencement of the experiment contained 31.2 per cent of peel, but as the storage period advanced a definite tendency of increase in peel percentage was noted up to six weeks attaining the highest average value of 35.1 per cent, whence it showed downward trend for the next two fortnightly intervals. It was succeeded again by a secondary rise and fall after 12 and 14 weeks respectively.

Rainy-season crop. The relative proportion of peel in the fruit of rainy-season crop was not much influenced by the temperature of 35°-38°F even after storage for ten weeks (Table 4). In fact, the ultimate peel percentage of 27.1 per cent at this temperature was slightly lower than the initial value. The mean value of 28.4 per cent for the entire storage period was more close to the initial value. But storage at higher temperatures tended to raise the peel fraction significantly. Most conspicuous increase in peel percentage was noticed at the highest storage temperature of 47°-50°F where it attained the highest value of 34.4 per cent after ten weeks.

The influence of storage on peel percentage was small but significant. Peel percentage increased up to four weeks and thereafter declined.

The interaction of temperature with period was also significant. It meant that the progressively higher storage temperatures which tended to increase the peel percentage were unusually effective in this respect during the later stages of storage.

'Nagpur' Mandarin Orange

Main-season crop. The proportion of peel in 'Nagpur' orange was little affected by storage at the two lower temperatures, viz. 35°-38°F and 39°-42°F (Table 5). Actually, the marginal mean over 14 weeks' storage at 39°-42°F was slightly lower than that at 35°-38°F, the two values being 27.75 and 28.35 per cent respectively. These compared quite favourably with the initial value of 26.7 per cent. The higher storage temperature of 42°-45°F was attended by more rapid increase in peel percentage during early stages. At the highest storage temperature of 47°-50°F there was still a more progressive and persistent increase in peel percentage throughout the storage period of 14 weeks ending in the final value of 35.1 per cent and overall fortnightly mean of 31.67 per cent.

On the whole, there was a common increase in peel percentage up to six weeks resulting in the period mean to rise from 26.7 to 30.2 per cent. Subsequently, the peel percentage increased at the highest storage temperature of 47°-50°F only.

Table 5. PEEL CONTENT OF 'NAGPUR' MANDARIN ORANGE (PEEL PERCENTAGE) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks									Mean C.D.
	0	2	4	6	8	10	12	14		
Main-season crop										± 1.34
35°-38°F	26.7	26.9	28.4	28.9	27.6	30.3	30.2	27.8	28.35	
39°-42°F	26.7	27.3	27.2	28.3	28.7	28.4	26.7	28.7	27.75	
42°-45°F	26.7	28.0	30.4	31.5	32.1	30.8	31.2	30.4	30.14	
47°-50°F	26.7	29.7	30.7	32.1	32.2	32.3	34.6	35.1	31.67	
Mean C.D. ± 1.90	26.7	28.0	29.2	30.2	30.2	30.5	30.7	30.5	—	
Rainy-season crop										± 1.45
35°-38°F	25.7	25.6	25.6	25.7	24.1	24.3	—	—	25.17	
39°-42°F	25.7	25.8	26.9	27.2	26.9	25.2	—	—	26.28	
42°-45°F	25.7	25.9	25.1	25.4	26.1	27.8	—	—	26.00	
47°-50°F	25.7	26.7	25.4	27.5	28.1	29.9	—	—	27.1	
Mean C.D. ± 1.78	25.70	26.00	25.75	26.45	26.30	26.80	—	—	—	

Rainy-season crop. The average peel percentage increased from 25.17 to 27.21 per cent with graded rise in storage temperature from 35°-38°F to 47°-50°F (Table 5). Peel percentage of 24.3 at 35°-38°F showed a slight decline from the initial value of 25.7 possibly owing to slight shrivelling up of the rind following low temperature injury. Peel percentage at 39°-42°F after ten weeks was nearly the same as at the beginning. At the next higher storage temperature of 42°-45°F the initial value of peel percentage was exceeded in the last two fortnightly intervals, whereas at the highest storage temperature of 47°-50°F this excess was noticeable in the last three intervals. The highest value of 29.9 per cent for peel was recorded at the highest storage temperature after ten weeks.

Table 6. PEEL CONTENT OF THE 'SATHGUDI' SWEET ORANGE DURING
STORAGE AT DIFFERENT TEMPERATURES (PEEL PERCENTAGE)

Storage temperature	Storage period in weeks											Mean C.D. ± 1.36
	0	2	4	6	8	10	12	14	16	18	20	
35°-38°F	24.3	26.7	23.6	27.4	29.3	25.6	25.8	29.1	25.7	28.5	30.2	26.93
39°-42°F	24.3	27.3	26.6	29.1	27.5	31.7	28.3	27.4	30.5	28.6	29.2	28.23
42°-45°F	24.3	26.3	24.6	31.7	28.3	30.4	28.2	29.1	31.1	3.16	32.6	28.93
47°-50°F	24.3	25.4	27.0	29.8	27.5	29.8	28.4	27.7	31.1	34.4	32.6	28.90
Mean C.D. ± 2.09	24.30	26.42	25.45	29.50	28.12	29.37	27.67	28.32	29.60	30.77	31.15	

Sathgudi' Sweet Orange

Higher storage temperature tended to cause greater increase in peel percentage (Table 6). Of course, the maximum increase of 1.3 per cent occurred with the first rise in storage temperature from 35°-38°F to 39°-42°F. The actual average values of peel percentage over 20 weeks worked out to 26.93 and 28.25 per cent respectively for these temperatures. The effect of further rise in storage temperature to 42°-45°F was small. The highest storage temperature of 47°-50°F was only as effective in this respect as 42°-45°F.

Storage duration also showed similar quantitative effect on peel percentage in so far as from the initial mean value of 24.30 per cent, this fraction gradually increased to 31.15 per cent with 20 weeks' storage.

JUICE CONTENT**'Coorg' Mandarin Orange**

Main-season crop. Whereas the peel percentage showed an upward trend with storage period, the juice percentage recorded a progressive decline throughout (Table 7). Juice percentage remained higher under the two lower storage temperatures of 35°-38°F and 39°-42°F. In fact, the percentage of juice in fruit on fresh weight basis Table 7. JUICE CONTENT OF 'COORG' MANDARIN ORANGE (JUICE PERCENTAGE)

DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									± 2.33
35°-38°F	47.6	48.1	45.4	48.1	42.2	44.3	42.0	44.8	45.6
39°-42°F	47.6	46.7	47.5	46.0	49.4	44.5	48.3	46.2	47.0
42°-45°F	47.6	43.0	45.0	48.5	46.3	47.5	42.9	40.3	45.2
47°-50°F	47.6	43.8	44.5	43.7	45.9	42.9	40.6	39.6	43.6
Mean C.D. ± 3.31	47.6	45.4	45.7	46.6	45.9	44.8	43.4	42.7	
Rainy-season crop									± 2.00
35°-38°F	51.7	55.3	55.7	56.5	54.5	56.1	—	—	55.0
39°-42°F	51.7	55.5	55.6	56.0	52.6	53.4	—	—	54.1
42°-45°F	51.7	57.4	54.1	52.5	52.4	51.9	—	—	53.3
47°-50°F	51.7	51.6	48.5	51.8	52.7	48.2	—	—	50.8
Mean C.D. ± 2.44	51.7	54.9	53.5	54.2	53.1	52.4			

at 39°-42°F exhibited only a small reduction from 47.6 to 46.2 for the entire storage period of 14 weeks. At the higher storage temperature of 42°-45°F the juice percentage showed a marked decline beyond ten weeks' storage and at 47°-50°F the decline occurred a fortnight earlier.

Rainy-season crop. At 35°-38°F, where the lowest peel percentage of 28.4 was recorded, the corresponding value of 55.0 per cent juice was noted to be the highest. Likewise, the storage temperature of 47°-50°F was attended by the highest peel portion of 32.5 per cent and the lowest juice content of 50.8 per cent. Thus the increased loss in percentage of juice at higher temperature was correspondingly reflected in higher percentage of peel and vice-versa.

The duration of storage did not show straight time trend in juice content averaged over different temperatures. It increased from 51.7 per cent to 54.9 per cent during the first fortnight and more or less maintained this level up to six weeks after which it gradually declined to 52.4 per cent in ten weeks.

'Nagpur' Mandarin Orange

Main-season crop. Under the two lower temperature ranges the reduction in juice content was not serious even up to 12 weeks' storage. The decrease in juice percentage was rather rapid at 42°-45°F and more so at 47°-50°F, attaining the values of 49.3 and 46.8 per cent respectively after 12 weeks against the initial value of 56.2 per cent. With another fortnight's storage at 47°-50°F the juice content dropped to 41.0 per cent, indicating thereby an excessive desiccation of the pulp ball. Taking all the storage temperatures together, the juice percentage of 'Nagpur' orange progressively declined from 56.2 per cent in the beginning to 47.5 per cent at the end of 14 weeks (Table 8).

Rainy-season crop. Storage period made little impact on the percentage of juice in fruit during the ten weeks of storage studies. From 50.40 per cent at the commencement, the juice content just came down to 49.40 per cent at the end. Likewise, the first three storage temperatures also left this character unaffected. It was only at the highest storage temperature of 47°-50°F that the juice percentage gradually declined from 50.4 to 47.3 per cent during the entire storage period.

'Sathgudi' Sweet Orange

The storage temperatures employed showed no straight and simple quantitative effects on this character as the mean juice percentage recorded for the rising order of temperatures was 45.80, 44.93, 47.60 and 46.16. The linear trend was greatly marked and even the

residual variation was not substantial. Since the main objective of the investigation was to determine a suitable temperature for storage purposes, the application of 't' test was perfectly valid. On this assumption the temperature range of 42°-45°F with 47.60 per cent of juice content was significantly better than the next lower temperature range of 39°-42°F which had only 44.93 per cent of juice. When compared with the lowest temperature range of 35°-38°F, the 42°-45°F range narrowly missed significance. An equally valid comparison of the two lower temperature ranges against the two higher ones was also found to be significant showing the greater suitability of higher temperature ranges employed herein.

Table 8. JUICE CONTENT OF 'NAGPUR' MANDARIN ORANGE (JUICE PERCENTAGE) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									± 1.69
35°-38°F	56.2	55.9	55.7	54.1	53.2	54.1	51.1	53.0	54.16
39°-42°F	56.2	56.0	55.5	54.8	54.1	54.0	53.6	47.8	54.00
42°-45°F	56.2	53.4	50.9	51.6	50.8	49.4	49.3	48.3	51.24
47°-50°F	56.2	52.6	52.0	50.4	49.1	48.7	46.8	41.0	49.60
Mean C.D. ± 2.39	56.2	54.5	53.5	52.7	51.8	51.6	50.2	47.5	—
Rainy-season crop									± 1.06
35°-38°F	50.4	49.3	48.8	52.6	49.3	51.1	—	—	50.25
39°-42°F	50.4	51.2	48.5	51.2	52.5	51.4	—	—	50.95
42°-45°F	50.4	50.8	50.7	49.8	52.2	47.8	—	—	50.28
47°-50°F	50.4	49.8	48.6	48.3	49.2	47.3	—	—	48.93
Mean C.D. ± 2.03	50.40	50.27	49.15	50.60	50.80	49.40	—	—	—

The 'Sathgudi' sweet orange showed a progressive decline in juice content with the passage of time in storage. From the initial mean value of 52.70 per cent it ultimately touched the lowest value of 38.02 per cent after 20 weeks. The decline in juice percentage was steep but not uniform (Table 9).

MOISTURE CONTENT OF JUICE

'Coorg' Mandarin Orange

Main-season crop. The moisture content of juice did not suffer large quantitative changes during storage, though the individual effects

Table 9. JUICE CONTENT OF 'SATHGUDI' SWEET ORANGE (JUICE PERCENTAGE) DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks											Mean C.D. ± 2.00
	0	2	4	6	8	10	12	14	16	18	20	
35°-38°F	52.7	52.1	53.9	49.3	45.7	48.0	46.5	40.6	38.3	40.1	36.7	45.80
39°-42°F	52.7	52.3	49.6	48.4	52.6	42.7	44.5	39.5	38.8	38.0	35.2	43.93
42°-45°F	52.7	49.9	53.4	46.9	50.4	49.4	46.3	47.9	43.0	42.1	41.6	47.60
47°-50°F	52.7	52.6	52.2	52.8	44.4	47.7	47.2	42.1	39.4	38.1	31.6	46.16
Mean C.D. ± 3.39	52.70	52.72	52.27	49.35	48.27	46.95	46.12	42.52	39.87	39.57	38.02	

of different storage temperatures were quite evident (Table 10). The mean moisture percentage in juice over fourteen weeks' storage ranged from 85.7 to 84.6, the higher value being associated with the lower storage temperature. Under the lowest storage temperature range of 35°-38°F, the water fraction in juice at the end of four weeks' storage came down from 86.6 to 85.2 per cent. Beyond this stage, the moisture content of juice more or less remained the same under this storage temperature. A similar initial trend of reduction in moisture percentage of juice was observed under the next higher storage temperature of 39°-42°F, but it further declined to 84.6 per cent at the end of eight weeks. The storage temperature of 42°-45°F had the same effect on the moisture content of juice as the 39°-42°F. The highest storage temperature of 47°-50°F showed a loss of about 2 per cent at the end of four weeks beyond which the moisture content of juice showed only sampling variations. The cardinal point of moisture percentage in juice was that it tended to establish early a stage of equilibrium in respect of particular storage temperature after which it showed no marked change with the extension of storage period up to 14 weeks.

Table 10. PERCENTAGE OF MOISTURE IN THE JUICE OF 'COORG' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									±0.59
35°-38°F	86.6	86.0	85.2	85.2	85.2	85.7	85.0	85.7	85.7
39°-42°F	86.6	85.2	85.1	85.2	84.6	83.3	85.0	84.1	84.9
42°-45°F	86.6	86.7	85.8	85.4	84.2	83.5	83.7	84.9	85.1
47°-50°F	86.6	86.5	84.7	83.7	84.5	83.4	83.0	84.3	84.6
Mean C.D. ±0.83	86.6	86.1	85.2	84.9	84.6	83.9	84.2	84.7	—
Rainy-season crop									±0.44
35°-38°F	90.2	90.7	90.0	89.5	89.7	88.4	—	—	89.8
39°-42°F	90.2	90.7	90.0	89.7	89.0	89.5	—	—	89.8
42°-45°F	90.2	90.15	89.2	89.2	89.3	89.1	—	—	89.6
47°-50°F	90.2	90.2	89.2	90.2	89.7	88.9	—	—	89.7
Mean C.D. ±0.54	90.2	90.5	89.6	89.6	89.4	89.0	—	—	—

Table 11. MOISTURE PERCENTAGE IN THE JUICE OF 'SATHGUDI' SWEET
ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks											Mean C.D. ±0.48
	0	2	4	6	8	10	12	14	16	18	20	
35°-38°F	87.2	86.9	88.2	86.5	85.5	86.0	84.0	85.2	85.5	84.4	82.0	85.58
39°-42°F	87.2	87.0	84.4	86.2	85.2	85.5	82.9	82.5	83.2	83.8	82.2	84.55
42°-45°F	87.2	87.2	86.4	85.8	84.6	84.6	85.4	86.4	86.5	83.6	83.5	85.56
47°-50°F	87.2	88.0	85.2	86.1	84.7	86.2	84.1	83.5	86.0	83.6	84.9	85.41
Mean C.D. ±1.36	87.20	87.27	86.05	86.15	85.00	85.57	84.10	84.40	85.30	83.85	83.15	—

Rainy-season crop. Storage temperatures did not show any individual effect over the entire period on the moisture content of juice as judged from the mean values, which ranged from 89.6 to 89.8 per cent. On the other hand, the time factor manifested a strong linear effect indicating that the water fraction of juice gradually decreased with the prolongation of storage period. The gradient of fall was rather low. The mean moisture content of 90.2 per cent in the beginning was reduced to 89.0 per cent at the end of 10 weeks' storage, indicating a loss of only 1.2 per cent.

'Sathgudi' Sweet Orange

The effect of storage temperature on moisture percentage in juice was not well defined (Table 11). There was an unexplainable aberration in this character at 39°-42°F with an average value of 84.55 per cent which was significantly less than the other three storage temperatures.

The moisture content of juice showed a regular fall during storage. The initial value of 87.20 per cent gradually declined to 83.15 per cent after 20 weeks.

Table 12. PERCENTAGE OF TOTAL SOLUBLE SOLIDS IN JUICE OF 'COORG' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									
									±0.52
35°-38°F	13.3	12.8	14.2	14.5	14.2	13.2	14.0	13.2	13.7
39°-42°F	13.3	14.6	14.6	14.2	14.2	14.88	14.0	14.0	14.2
42°-45°F	13.3	13.2	14.0	14.5	15.0	15.0	15.0	14.8	14.4
47°-50°F	13.3	13.2	14.8	16.0	14.6	15.0	16.0	14.6	14.7
Mean C.D. ±0.74	13.3	13.5	14.4	14.8	14.5	14.5	14.7	14.1	—
Rainy-season crop									
									±0.44
35°-38°F	9.8	9.0	9.5	8.8	10.8	11.4	—	—	10.1
39°-42°F	9.8	10.0	9.7	10.5	11.0	11.0	—	—	10.3
42°-45°F	9.8	9.9	10.7	10.8	11.5	11.5	—	—	10.7
47°-50°F	9.8	9.0	10.2	10.8	10.6	11.8	—	—	10.4
Mean C.D. ±0.54	9.8	9.5	10.0	10.5	11.0	11.4	—	—	—

TOTAL SOLUBLE SOLIDS IN JUICE

As the strained juice is composed mainly of water and total soluble solids, these two factors are complementary in nature and the remarks on one automatically reflect the changes in the other. The diminishing water fraction is accompanied by a corresponding rise in the percentage of total soluble solids in juice.

The most important components of total soluble solids such as the reducing sugar, total titratable acidity expressed as anhydrous citric acid, and the ascorbic acid were studied in detail.

'Coorg' Mandarin Orange

The results for the main and rainy-season crops are summarised in Table 12. The effect of storage temperature on the total soluble solids in juice was slightly more marked than on the moisture percentage of juice. The total soluble solids increased with the increasing storage temperature up to the range of 42°-45°F. A slight decline in the mean value of total soluble solids was noticed at 47°-50°F.

The duration of storage, however, exercised more pronounced effect than the storage temperatures on the total soluble solids in juice.

Table 13. PERCENTAGE OF TOTAL SOLUBLE SOLIDS IN JUICE OF 'NAGPUR'

MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									
									±0.32
35°-38°F	12.0	12.2	12.7	11.8	12.6	13.0	12.2	12.6	12.39
39°-42°F	12.0	11.8	12.1	12.6	12.5	13.3	12.8	12.0	12.39
42°-45°F	12.0	12.4	11.8	12.8	12.4	12.9	12.7	12.6	12.45
47°-50°F	12.0	11.8	12.2	12.4	12.7	12.6	12.5	12.7	12.36
Mean C.D. ±0.46	12.0	12.1	12.2	12.4	12.6	13.0	12.6	12.5	—
Rainy-season crop									
									±0.42
35°-38°F	9.3	9.2	9.3	9.7	11.0	10.5	—	—	9.83
39°-42°F	9.3	9.4	9.3	9.4	10.0	10.3	—	—	9.62
42°-45°F	9.3	9.3	9.5	9.4	9.3	10.2	—	—	9.50
47°-50°F	9.3	9.4	9.7	9.6	10.4	11.2	—	—	9.93
Mean C.D. ±0.54	9.30	9.32	9.45	9.52	10.18	10.55	—	—	—
Fortnightly increase	—	0.02	0.13	0.07	0.66	0.37			

Table 14. PERCENTAGE OF TOTAL SOLUBLE SOLIDS IN THE JUICE OF
'SATHGUDI' SWEET ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks											Mean C.D. ±0.65
	0	2	4	6	8	10	12	14	16	18	20	
35°-38°F	12.5	12.5	11.8	12.8	14.0	14.0	15.0	14.0	14.0	15.2	16.5	13.84
39°-42°F	12.5	12.5	15.0	13.5	14.9	14.8	15.8	16.5	16.0	15.2	16.7	14.91
42°-45°F	12.5	12.6	13.5	13.7	14.4	14.5	14.0	13.8	13.5	14.8	15.5	13.90
47°-50°F	12.5	12.8	14.5	13.6	14.7	13.2	15.2	15.8	13.8	16.0	14.0	14.20
Mean. C.D.	± 1.08	12.50	12.60	13.70	13.40	14.50	14.12	15.00	15.02	14.22	15.45	15.67

But for a slight decrease during the first fortnight in the case of rainy-season crop this fraction continued to increase progressively.

'Nagpur' Mandarin Orange

Main-season crop. Storage temperatures did not exhibit any individual effect on the total soluble solids in the juice of 'Nagpur' orange as the mean values for the different temperature ranges varied only between 12.36 and 12.45 per cent. The effect of storage period was, however, more marked showing a gradual but consistent increase in the mean value of total soluble solids from 12.0 to 13.0 per cent in the ten weeks (Table 13). Subsequently, however, it declined to 12.5 per cent in the last four weeks of storage.

Rainy-season crop. This character also showed little temperature effects. The mean value of 9.83 per cent for total soluble solids at 35°-38°F increased only to 9.93 per cent at the highest storage temperature of 47°-50°F (Table 13).

The effect of storage period on total soluble solids was well marked showing a concentration from 9.30 to 10.55 per cent after ten weeks. The rate of increase in concentration was, however, not uniform over the different fortnightly intervals. A good deal of variation in total soluble solids could, therefore, be attributed to these erratic trends.

'Sathgudi' Sweet Orange

The percentage of total soluble solids in the juice of 'Sathgudi' orange, averaged over the fortnightly determinations, was found to be 13.84, 14.91, 13.90 and 14.20 respectively for the four storage temperature ranges employed (Table 14). These are highly individualistic effects of different storage temperatures, which could not be explained.

On the other hand, the effect of storage duration was simple inasmuch as it presented a uniform and progressive increase in the concentration of juice depending upon the length of storage period. From the initial value of 12.50 per cent, the total soluble solids increased to 16.67 per cent at the end of 20 weeks' storage.

REDUCING SUGARS

'Coorg' Mandarin Orange

Main-season crop. The effect of storage temperature on the percentage of reducing sugars was simple inasmuch as this constituent showed progressively higher concentration with the increase in storage temperature (Table 15). The greatest rise in the concentration of reducing sugars from 5.19 per cent to 5.56 per cent was noted with the first rise in temperature range from 35°-38°F to 39°-42°F. Further increase in storage temperature caused a small though positive change in this character.

The duration of storage also had a very conspicuous effect on the concentration of reducing sugars. Up to six weeks, this fraction continued to increase and reached the highest average value of 6.02 per cent. After eight weeks there was a sudden drop in reducing sugars to 5.60 per cent, succeeded again by secondary rise after ten weeks which in turn was followed by a slow and gradual decline up to the end of storage period.

Rainy-season crop. The percentage of reducing sugars increased as the storage temperature was raised (Table 16). From the mean value of 2.70 per cent at 35°-38°F it rose to 3.25 per cent at 47°-50°F. The effect of storage period was also similar in so far as the reducing sugars, on the whole, showed a tendency of increase with the increasing duration. But the increase at different intervals of storage was not uniform.

Table 15. CHEMICAL COMPOSITION OF THE JUICE OF 'COORG' MANDARIN ORANGE (MAIN-SEASON CROP) DURING STORAGE AT DIFFERENT TEMPERATURES

Particulars	Reducing sugars (%)	Titrateable acidity (%)	T.S.S./Acid ratio	Ascorbic acid in juice (mg/100 ml)
Storage temperature				
35°-38°F	5.19	0.66	21.0	25.25
39°-42°F	5.56	0.69	20.5	26.85
42°-45°F	5.59	0.67	21.6	26.37
47°-50°F	5.64	0.71	21.3	30.10
C.D.	+0.35	+0.04	+1.23	+ 2.07
Storage period				
0 Week(s)	4.60	0.76	17.5	27.60
2 "	4.95	0.67	20.2	27.32
4 "	5.78	0.73	19.7	29.30
6 "	6.02	0.72	20.5	30.88
8 "	5.60	0.72	20.0	28.72
10 "	5.85	0.71	20.5	27.12
12 "	5.72	0.64	23.3	25.07
14 "	5.62	0.52	27.3	21.17
C.D.	±0.50	±0.56	±1.74	±2.93

TITRATABLE ACIDITY

'Coorg' Mandarin Orange

Main-season crop. The total acidity in juice averaged over the fortnightly reading for the entire storage period also showed the effect of individual storage temperatures. The acid content of 0.69 per cent at 39°-42°F was appreciably higher than 0.66 per cent at 35°-38°F. The highest value of 0.71 per cent was recorded at 47°-50°F (Table 15).

The effect of storage period averaged over the four storage temperatures employed showed a gradual decline in the acid content of juice from 0.76 per cent at the commencement of storage to 0.71 per cent at the end of ten weeks. Low value of 0.67 per cent for acidity after two week's storage could be due either to chance variation of sampling or to a continued process of fruit maturity after picking. After ten weeks' storage the fall in acidity was rather pronounced and attained a value as low as 0.52 per cent towards the end of storage period.

Rainy-season crop. Storage temperatures had no individual effects on the percentage of acidity in juice, but the prolongation of storage period caused a continuous fall from the initial value of 0.78 per cent Table 16. CHEMICAL COMPOSITION OF THE JUICE OF 'COORG' MANDARIN ORANGE (RAINY-SEASON CROP) DURING STORAGE AT DIFFERENT TEMPERATURES

Particulars	Reducing sugars (%)	Titratable acidity (%)	T.S.S./Acid ratio	Ascorbic acid in juice (mg/100 ml)
Storage temperature				
35°-38°F	2.70	0.63	16.35	33.88
39°-42°F	2.92	0.64	16.23	35.33
42°-45°F	3.10	0.64	16.17	33.67
47°-50°F	3.25	0.64	16.30	35.43
C.D.	±0.29	±0.048	±1.63	±2.26
Storage period				
0 Week(s)	2.10	0.78	12.50	37.50
2 „	2.10	0.67	14.15	34.58
4 „	3.03	0.61	16.48	36.32
6 „	3.65	0.62	16.77	35.70
8 „	3.40	0.62	18.12	31.92
10 „	3.68	0.58	19.58	31.75
C.D.	—0.35	—0.60	— 2.00	— 2.77

to 0.59 per cent in ten weeks. Most of the reduction in acidity occurred during the first four weeks after which no marked change was noted except at the last stage (Table 16).

'Nagpur' Mandarin Orange

Main-season crop. In the juice of 'Nagpur' orange of the main-season crop, acidity was best preserved not at the lowest storage temperature range of 35°-38°F but at the next higher temperature of 39°-42°F (Table 17). At this favourable temperature, acidity showed an upward trend up to ten weeks of storage touching the highest value of 0.56 per cent. It was followed by a decline to 0.47 per cent after 14 weeks, which value was still higher than that at any other temperature. The increase in acidity at 35°-38°F could only be noted up to six weeks, in case of the two higher temperature ranges this tendency was visible just up to four weeks of storage. This shows that the storage temperature of 39°-42°F was singularly the most favourable for preserving acidity.

Rainy-season crop. Over the range of storage temperatures employed no individual temperature effects could be seen in the mean values of acidity as given in the last column of Table 17. The dura-

Table 17. TITRATABLE ACIDITY IN THE JUICE OF 'NAGPUR' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean \pm C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									± 0.05
35°-38°F	0.48	0.43	0.52	0.51	0.42	0.46	0.40	0.38	0.45
39°-42°F	0.48	0.47	0.48	0.51	0.53	0.56	0.45	0.47	0.49
42°-45°F	0.48	0.58	0.49	0.42	0.41	0.38	0.39	0.44	0.45
47°-50°F	0.48	0.51	0.48	0.44	0.46	0.40	0.47	0.38	0.45
Mean C.D.	± 0.07	0.48	0.49	0.49	0.47	0.45	0.45	0.42	0.42
Rainy-season crop									± 0.133
35°-38°F	0.97	0.95	0.94	0.89	0.87	0.86			0.913
39°-42°F	0.97	0.92	0.88	0.82	0.83	0.81			0.872
42°-45°F	0.97	0.97	0.95	0.84	0.85	0.80			0.897
47°-50°F	0.97	0.95	0.96	0.87	0.82	0.81			0.897
Mean C.D.	± 0.164	0.970	0.948	0.933	0.855	0.843	0.820		

tion of storage, on the other hand, was found to decrease acidity progressively from 0.97 to 0.82 per cent during ten weeks.

'Sathgudi' Sweet Orange

Within the range of temperatures employed storage temperature did not show any marked effect on the acid content of juice. The three higher storage temperatures were almost identical in their effect and, on the whole, were responsible for slightly higher acid content than the lowest temperature of 35°-38°F (Table 18).

During storage, the mean value of titratable acidity in juice showed an increase from 0.480 to 0.577 per cent over the early storage period of ten weeks. It was followed by a gradual decline which continued towards the end of the storage period of 20 weeks attaining the lowest value of 0.427 per cent.

Table 18. TOTAL ACIDITY IN THE JUICE OF 'SATHGUDI' ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage period	Percentage of titratable acidity at				Mean ± C.D.
	35°-38°F	39°-42°F	42°-45°F	47°-50°F	
					± 0.052
0 week(s)	0.48	0.48	0.48	0.48	0.480
2 "	0.56	0.54	0.48	0.58	0.540
4 "	0.49	0.51	0.56	0.52	0.520
6 "	0.54	0.45	0.51	0.51	0.502
8 "	0.49	0.57	0.60	0.56	0.555
10 "	0.55	0.61	0.56	0.59	0.577
12 "	0.51	0.61	0.56	0.57	0.562
14 "	0.46	0.52	0.49	0.57	0.510
16 "	0.45	0.50	0.47	0.38	0.450
18 "	0.40	0.45	0.48	0.42	0.437
20 "	0.42	0.44	0.46	0.39	0.427
Mean					
C.D.	±0.031	0.486	0.516	0.513	0.506

The interaction of storage temperature with storage duration was not strongly marked, although the drop in acidity at the highest temperature of 47°-50°F during the later stages became very prominent.

TOTAL SOLUBLE SOLIDS/ACID RATIO

Coorg' Mandarin Orange

Main-season crop. Since total soluble solids representing mostly the sugar fraction impart sweetness to the fruit and the total titratable acidity gives it sourness, the ratio of these two important constituents is usually taken as the reliable index of the organoleptic quality of fruit.

It would be seen from Table 15 that, within the range employed, storage temperatures had no differential effect on this character of juice. On the other hand, the effect of storage period averaged over storage temperatures was very striking. There was a significant increase in this ratio within the first two weeks attaining a mean value of 20.2 against the initial figure of 17.5. Thereafter, this ratio remained virtually stable up to ten weeks whence it suddenly shot up to 23.3 after 12 weeks and went up as high as 27.3 by the end of the next fortnight.

Rainy-season crop. This character was also little affected by the varying storage temperatures, but the storage duration brought about a strong progressive increase in its value from 12.50 to 19.58 in the course of ten weeks (Table 16).

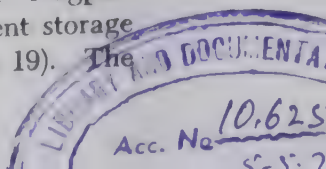
Nagpur' Mandarin Orange

Main-season crop. Derived data on T.S.S./Acid ratio are given in Table 19. The most outstanding feature was the unusual stability of this ratio at 49°-42°F over a storage period of ten weeks. A slight undertone in this ratio following the fourth week suggests even some improvement in this character. Only after 12 weeks' storage there was an appreciable rise in this value, but it was followed again by a decline to the normal value of 25 at the next stage.

Such stability in T.S.S./Acid ratio could be deemed to have been maintained for a period of six weeks only at the storage temperature of 35°-38°F, if the early rise following the commencement of storage was ignored and attributed to errors of sampling. Beyond six weeks, the rise in this ratio was very conspicuous.

The trends in T.S.S./Acid ratio at the two higher temperatures of 42°-45°F and 47°-50°F were almost identical in so far as these were marked by an initial drop during the first fortnight, recovery to the normal value after four weeks and sharp rise during the subsequent storage period. These fluctuations in the case of 42°-45°F were more sharply marked than at 47°-50°F.

Rainy-season crop. T.S.S./Acid ratio in the juice of 'Nagpur' range of the rainy-season crop gradually increased at different storage temperatures with the advancement of storage period (Table 19). The



rate of rise in this value was most steady in case of 39°-42°F. The relatively high value of about 12.5 was simultaneously attained after eight weeks at 35°-38°F and 47°-50°F, whereas no such tendency was noticeable at 35°-38°F. The intermediate temperature ranges had, on the whole, more salutary effect on this character.

'Sathgudi' Sweet Orange

Detailed data on T.S.S./Acid ratio are given in Table 20. It may be observed that at 35°-38°F the T.S.S./Acid ratio remained fairly stable during the early six weeks of storage, whence a regular and steady rise in the curve occurred up to 16 weeks. After 16 weeks the break in the sugar/acid blend was rather sudden and rise in the curve sharp.

Table 19. THE TOTAL SOLUBLE SOLIDS/ACID RATIO CONTENT IN THE JUICE OF 'NAGPUR' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean \pm C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									± 2.89
35°-38°F	25.0	28.4	24.4	23.1	30.0	28.3	30.5	33.2	27.9
39°-42°F	25.0	25.1	25.2	24.7	23.8	23.8	28.5	25.5	25.2
42°-45°F	25.0	21.4	24.1	30.5	30.2	33.9	32.5	28.6	28.3
47°-50°F	25.0	23.1	25.4	28.2	27.6	31.5	26.6	33.4	27.6
Mean									
C.D. ± 4.16	25.0	24.5	24.8	26.6	27.9	29.4	29.5	30.2	—
Rainy-season crop									± 0.54
35°-38°F	9.6	9.7	9.9	10.9	12.6	12.2			10.8
39°-42°F	9.6	10.2	10.6	11.5	12.0	12.7			11.1
42°-45°F	9.6	9.6	10.0	11.2	11.0	12.7			10.6
47°-50°F	9.6	9.9	10.1	11.0	12.7	13.8			11.2
Mean									
C.D. ± 0.66	9.6	9.9	10.2	11.2	12.1	12.9			—

stable during the early six weeks of storage, whence a regular and steady rise in the curve occurred up to 16 weeks. After 16 weeks the break in the sugar/acid blend was rather sudden and rise in the curve sharp.

At 39°-42°F, an increase in T.S.S. Acid ratio could be observed after four weeks' storage, which persisted for another fortnight.

The next higher storage temperature of 42°-45°F turned out to be most favourable for the preservation of T.S.S./Acid blend. The ultimate ratio of 33.5 attained after 20 weeks was the lowest among the various storage temperatures employed.

ASCORBIC ACID

'Coorg' Mandarin Orange

Main-season crop. The first three storage temperatures did not materially differ from one another in their effect on the ascorbic acid content of juice, although the temperature range of 39°-42°F had a comparatively higher ascorbic acid content with an average value of 26.85 mg/100 ml juice. The highest ascorbic acid content of 30.10 mg/100 ml of juice was, however, recorded under 47°-50°F (Table 15).

The ascorbic acid also increased with storage duration up to six weeks at which stage it registered the highest value of 30.88 mg/100 ml of juice but thenceforth it decreased, gradually at first but rapidly in the last two weeks, till it reached the lowest level of 21.17 mg at the end of 14 weeks' storage.

Table 20. TOTAL SOLUBLE SOLIDS/ACID RATIO IN THE JUICE OF 'SATHGUDI' SWEET ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage period	T.S.S./Acid ratio at				Mean ± C.D.
	35°-38°F	39°-42°F	42°-45°F	47°-50°F	
					± 3.18
0 week(s)	26.0	26.0	26.0	26.0	26.00
2 „	22.3	23.1	25.8	22.1	23.32
4 „	24.0	29.4	24.1	27.8	26.32
6 „	23.7	30.0	26.9	26.7	26.82
8 „	28.5	26.1	24.0	26.2	26.20
10 „	25.3	24.2	25.2	22.5	24.30
12 „	29.4	25.9	25.0	26.7	26.78
14 „	30.0	31.7	28.2	27.7	29.40
16 „	31.1	32.0	28.7	36.3	32.02
18 „	38.0	35.1	30.8	38.6	35.62
20 „	39.3	35.7	33.5	35.9	36.10
Mean C.D.	± 1.90 28.87	29.01	27.11	28.77	

Rainy-season crop. The different storage temperatures did not materially influence the ascorbic acid content of juice. With the advance in storage duration, however, ascorbic acid gradually declined from 37.50 to 31.75 mg/100 ml of juice during ten weeks. It may be noted that, even towards the close of the experiment, the ascorbic acid content remained fairly high (Table 16).

'Nagpur' Mandarin Orange

Main-season crop. Quantitative changes occurring in the ascorbic acid content of the juice of 'Nagpur' orange of the main-season crop during storage at different temperatures are given in Table 21. Like the T.S.S./Acid ratio, the greatest stability in ascorbic acid during storage was recorded at 39°-42°F despite a common decline in this constituent noted at all the storage temperatures employed. Even up to 12 weeks the ascorbic acid content at this temperature did not fall much below 25 mg/100 ml of juice. In contrast to this, the ascorbic acid content at the lowest storage temperature of 35°-38°F showed a sudden and substantial fall below 25 mg/100 ml of juice beyond six weeks' storage. The corresponding stage of a sudden decline in this character at 42°-45°F was noted a fortnight later, i.e., beyond eight weeks' storage. But the fruit maintained at the highest storage temperature of 47°-50°F presented a complex picture. Following the general initial decline in ascorbic acid content up to six weeks, there could be observed a stage of stability for another spell of six weeks.

Table 21. THE ASCORBIC ACID IN THE JUICE OF 'NAGPUR' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Storage period in weeks								Mean ± C.D.
	0	2	4	6	8	10	12	14	
Main-season crop									± 4.72
35°-38°F	32.1	29.0	26.1	25.7	22.8	22.2	21.2	20.9	25.0
39°-42°F	32.1	29.3	28.3	28.6	26.1	25.8	24.6	23.2	27.3
42°-45°F	32.1	31.0	26.0	25.8	25.4	23.2	20.0	19.7	25.4
47°-50°F	32.1	30.0	27.7	26.5	25.7	26.2	26.5	21.6	27.0
Mean									
C.D. ± 6.82	32.1	29.8	27.0	26.7	25.0	24.4	23.1	21.4	—
Rainy-season crop									± 3.46
35°-38°F	34.1	31.8	27.7	27.5	25.6	23.7			28.4
39°-42°F	34.1	31.8	35.0	33.6	35.0	33.9			32.9
42°-45°F	34.1	34.1	37.7	38.7	32.5	27.5			34.1
47°-50°F	34.1	33.1	31.8	35.2	26.2	25.0			30.9
Mean									
C.D. ± 4.26	34.1	32.7	33.1	33.8	31.8	27.5			—

After that a sudden drop in this value became marked. The maintenance of high values of ascorbic acid above 25 mg/100 ml of juice at 47°-50°F between the 6th and the 12th week of storage could be ascribed to the resistance of ascorbic acid to destruction as well as its concomitant concentration with excessive desiccation of fruit at this temperature.

Ratny-season crop. The ascorbic acid content during storage was the steadiest at 39°-42°F. Except for minor sampling fluctuations, little change could be said to have occurred. A complete contrast was provided by the lowest storage temperature of 35°-38°F where a regular downward trend was noted in this constituent throughout the storage period. At the higher storage temperatures of 42°-45°F and 47°-50°F, the ascorbic acid was well preserved up to six weeks, beyond which the combined adverse effect of storage duration and storage temperature strongly manifested itself in its precipitous decline (Table 21).

'Sathgudi' Sweet Orange

A tendency of slight increase in ascorbic acid during early stages of storage was unmistakably evident at all the storage temperatures

Table 22. ASCORBIC ACID CONTENT IN THE JUICE OF 'SATHGUDI' SWEET ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage period	Ascorbic acid (mg/100 ml juice) at				Mean ± C.D.
	35°-38°F	39°-42°F	42°-45°F	47°-50°F	
					± 3.67
0 weeks	62.7	62.7	62.7	62.7	62.70
2 "	65.0	61.0	67.0	62.5	63.87
4 "	57.0	67.3	62.7	65.1	63.02
6 "	68.2	63.6	68.2	68.2	67.05
8 "	66.2	66.6	67.4	62.7	65.72
10 "	65.8	62.5	68.8	61.1	64.55
12 "	64.6	60.0	61.2	62.7	62.12
14 "	60.3	61.5	62.0	62.5	61.57
16 "	54.3	60.4	61.4	57.1	58.30
18 "	52.8	58.6	59.1	54.3	56.02
20 "	53.3	54.2	56.0	55.5	54.75
Mean					—
C.D. ± 2.16	60.92	61.67	63.32	61.31	—

(Table 22). The point of declination was, however, not uniform following 6, 8, 10 and 16 weeks' storage, respectively, at the four ascending temperature ranges employed. The inception of this event had an important bearing on the subsequent storage life of fruit at these temperatures. After the initiation of this decline, fall in ascorbic acid was rather regular at the lowest storage temperature of 35°-38°F,

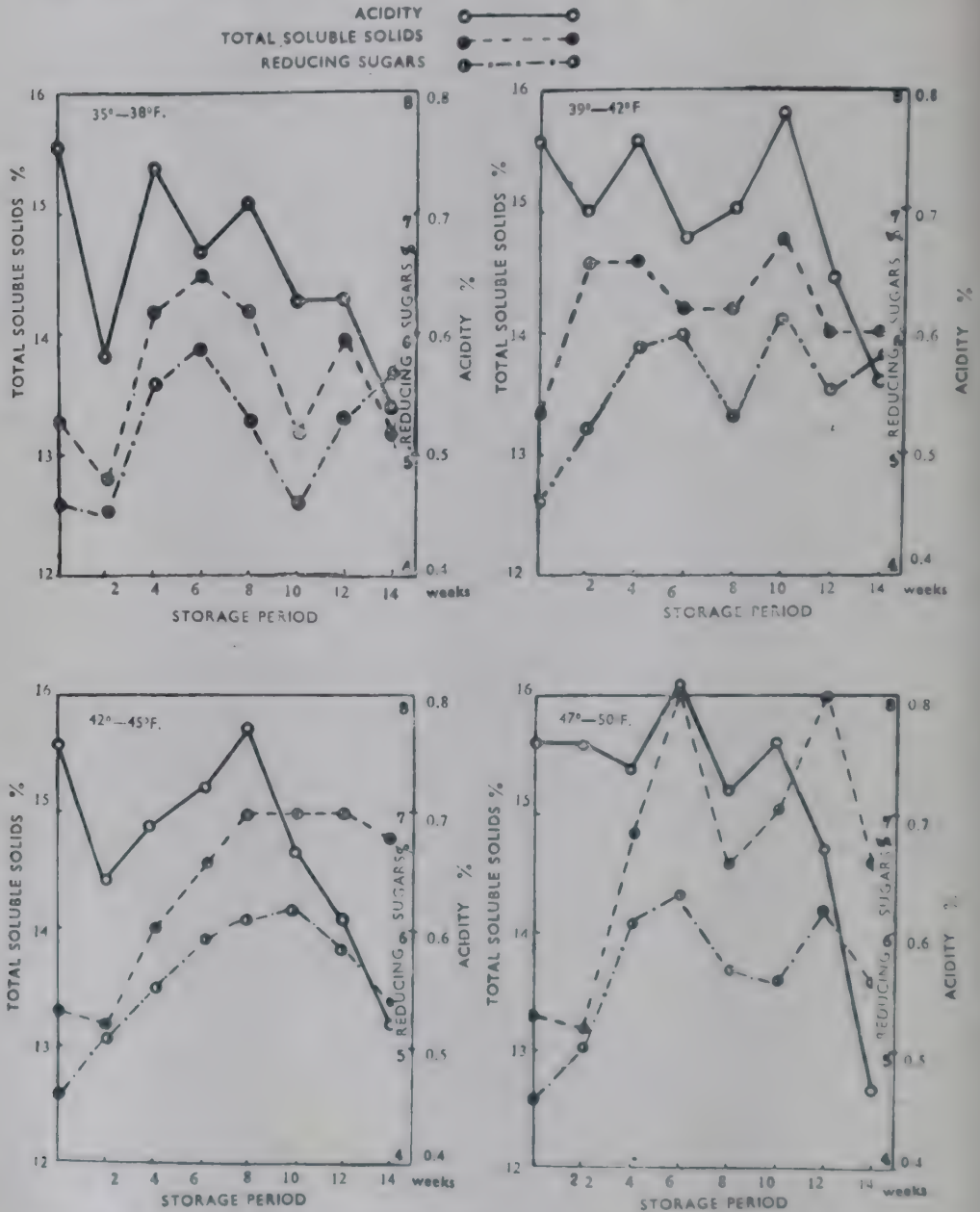


Fig. 4. Changes in total soluble solids, reducing sugars and titratable acidity in the juice of 'Coorg' mandarin orange (main season crop) during storage at different temperatures.

whereas in the remaining three temperatures a small spell of secondary rise in this character was noticeable following the climactic.

FRUIT QUALITY DURING STORAGE

'Coorg' Mandarin Orange

Main-season crop. Apart from the attractive appearance of orange, the most desirable characters of fruit quality constitute high juice content, high total soluble solids (mainly sugars) well blended with acidity, and high ascorbic acid value. A storage temperature which can effectively preserve these attributes of quality for the longest period can only be taken as the optimum one. With this end in view, the periodic changes observed in these salient features of fruit quality are presented in Figures 4 and 5.

At 35°-38°F, the total soluble solids as well as the reducing sugars continued to increase over the initial six-week period on account of the progressive loss of moisture from the fruit as well as owing to the conservation of disaccharides into simpler forms of sugars. Even accounting for the sampling error at the first fortnightly interval, apparently the rise in the concentration of sugars was gradual and did not ultimately attain as high a maximum as noticeable under other temperatures. This indicated a very favourable effect of the lowest temperature range on the preservation of juiciness of fruit during the early part of storage period. Further storage for another fortnight at this temperature resulted in the reduction of sugars under the impact of high rate of respiration. During all these eight weeks, the acidity varied around 0.7 per cent. Accordingly, the T.S.S./Acid ratio during this period showed a gradual increase from 17.5 to 20.0 which could normally be accepted. At the end of eight weeks, the ascorbic acid suddenly decreased to a value slightly below 25 mg which suggested that in addition to the normal adjustment process of moisture and soluble solids in juice some other factor had come into operation which adversely affected the ascorbic acid content in particular. Observations made at the next storage interval of ten weeks clearly manifested some serious disorganisation of fruit kept at this temperature as judged from the abnormally low values of total soluble solids and reducing sugars. Even the acidity showed disproportionately higher fall resulting in the deterioration of the sugar/acid blend. Further storage at this temperature led to rapid deterioration of fruit as indicated by the ascending curve for the blend and the descending curve for ascorbic acid.

The fruit stored at 39°-42°F also showed increase in the total soluble solids and reducing sugars during storage in the early stages. After six weeks, the reducing sugars still continued to increase, although

the corresponding values for total soluble solids and acidity showed a common depression. At the end of eight weeks' storage, an appreciable fall was noted in both these constituents. In the subsequent fortnight, however, there was again a noticeable increase in sugars as well as in acidity. As a result of these co-ordinated changes in sugars

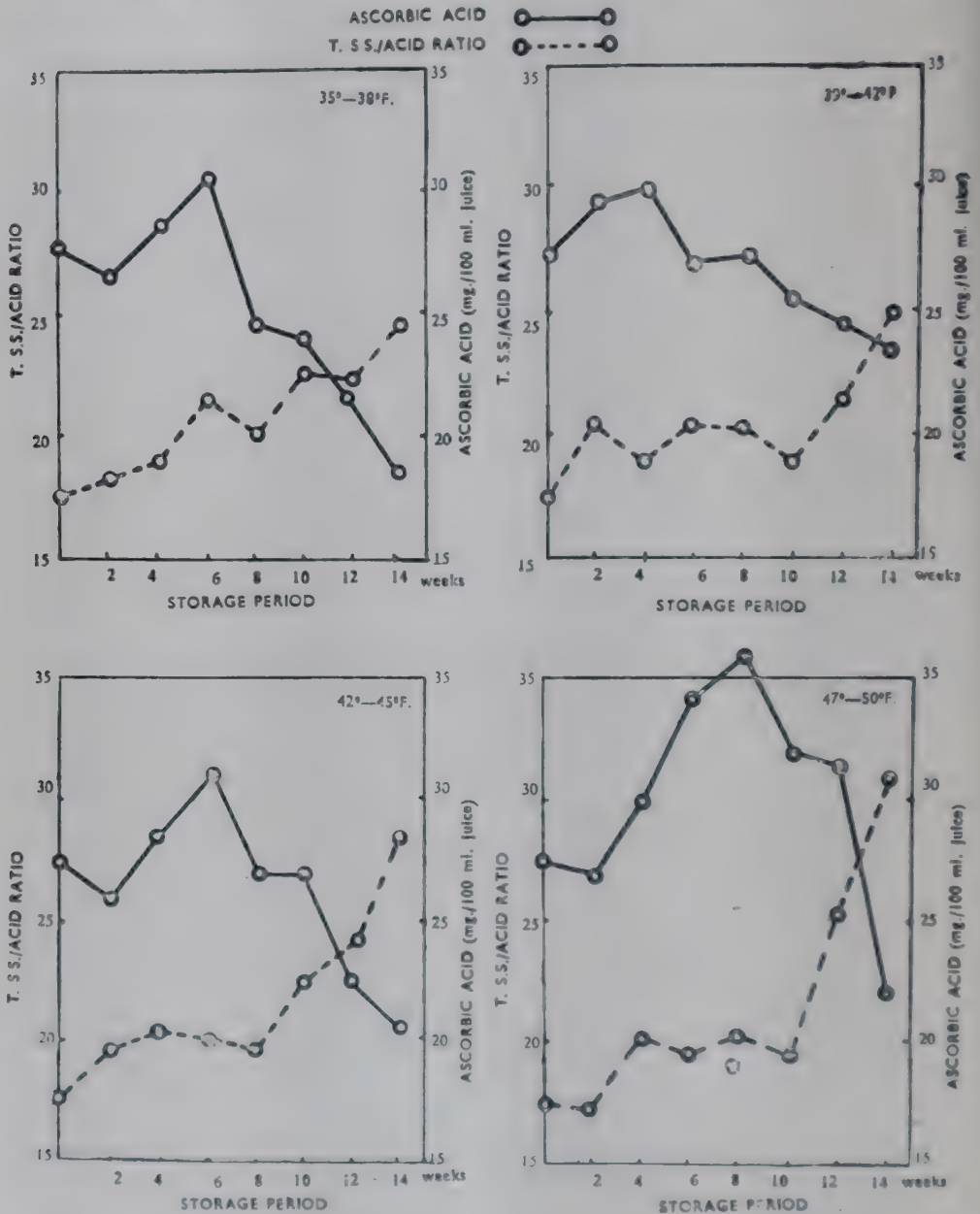


Fig. 5. Changes in the total soluble solids/acid ratio and ascorbic acid content in the juice of 'Coorg' mandarin orange (main-season crop) during storage at different temperatures.

and acidity up to ten weeks, the blend remained around the acceptable T.S.S./Acid ratio of about 20. Though the sugar/acid blend and the ascorbic acid content showed some negative trends after 12 weeks' storage, the magnitude of adverse tendencies was not large enough. This, together with the juicy character still well preserved, kept the fruit in acceptable condition.

The effect of storage temperature of 42°-45°F on the total soluble solids and reducing sugars was similar to that of the two lower storage temperatures during the early stages, but as the storage period advanced, the concentration effects became more marked because of greater loss of moisture from fruit at this higher storage temperature. The increase in sugars was progressive almost to the end of 12th week. The fall in acidity was, however, noted after eight weeks which continued rapidly during the later part of storage period. The values of T.S.S./Acid ratio and ascorbic acid at the eight weeks' stage also varies within acceptable limits. Even after ten weeks' storage, the quantitative value of these two characters looked favourable but the excessive loss in fruit weight that had occurred to the tune of 10 per cent by this time pointed to the virtual termination of its reasonable storage life. The 10-week storage stage of this temperature is comparable with the 12-week storage stage of 39°-42°F.

The highest storage temperature of 47°-50°F caused excessive concentration of the total soluble solids right from the 4th week onward and attained the maximum value of 16 per cent after six weeks. The percentage of reducing sugars also increased but it did not go beyond 6 per cent, the highest concentration it attained under the other three lower storage temperatures. At the critical stage of eight weeks, owing to rapid loss of moisture from fruit, the fraction of total soluble solids again showed a significant increase. The total acidity as well as the ascorbic acid remained fairly high up to 12 weeks for the same reason. The sugar/acid blend appeared to be optimum up to 10 weeks' storage but the cumulative loss in weight of fruit at this temperature had already amounted to a high value of 12.9 per cent pointing to the excessive shrivelling of fruit and loss of its juice. The optimum storage life of fruit at this temperature, therefore, had already passed and, by interpolation of results, nine weeks could perhaps be taken as the end point.

Rainy-season crop. A close study of the comparative values of different constituents of fruit quality (Fig. 6) revealed that in 'rainy-season' crop of 'Coorg' orange at no stage during 10 weeks' storage were the critical values exceeded as was found to be the case with the 'main season' crop already described. The fruit of the rainy-season crop under all storage temperatures contained sufficient acidity.

In spite of its gradual decrease with increase in the storage period, the minimum value of 0.55 per cent for acidity under 47°-50°F after 10 weeks' storage did not seriously break the sugar/acid blend. It

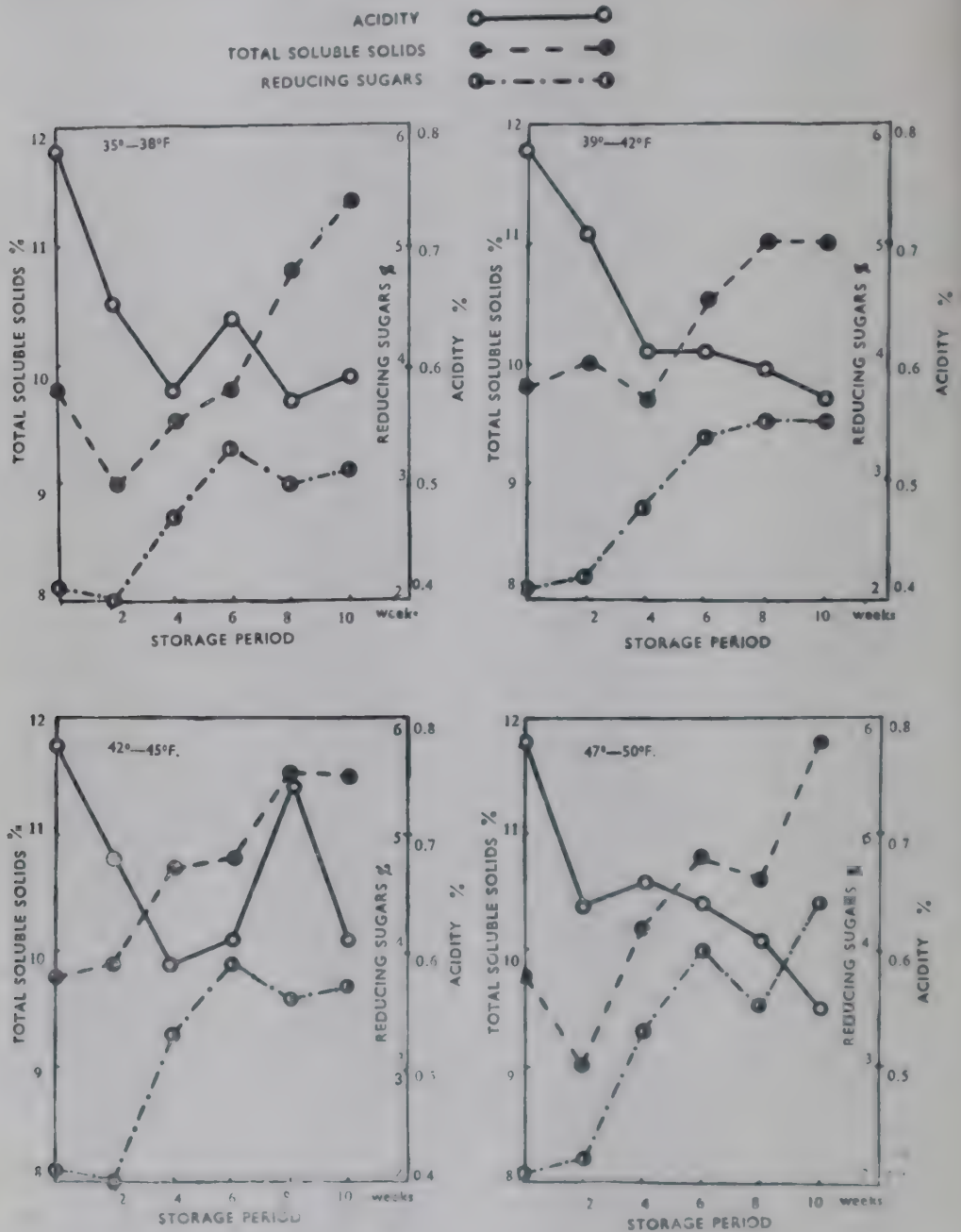


Fig. 6. Changes in total soluble solids, reducing sugars and titratable acidity in the juice of 'Coorg' orange (rainy-season crop) during storage at different temperatures.

was so because of low total soluble solids in the fruit of the rainy-season crop. Mostly the value of T.S.S./Acid ratio remained below 20. The minimum ascorbic acid of 30 mg/100 ml of juice at 35°-38°F even at the last stage was reasonably high. Hence, the rate of chemical changes and the actual proportion of important ingredients in the fruit of the rainy-season crop could not be considered to have acted as limiting factors for its optimum storage during the studies extending over ten weeks.

'Nagpur' Mandarin Orange

Main-season crop. The 'Nagpur' orange is inherently different from the 'Coorg' orange in fruit quality inasmuch as the former is comparatively richer in juice and ascorbic acid but poorer in total soluble solids and titratable acidity. Therefore, to determine the minimum acceptable quality and the maximum storage life, different standards shall have to be employed for these orange varieties.

Since the 'Nagpur' orange was very juicy to begin with and maintained it during storage except in the final stages at higher temperatures, this factor was not of much consequence in indicating the optimum storage life of this fruit. The changes in ascorbic acid and T.S.S./Acid ratio were thus left to be the only important criterion of fruit quality during storage.

It was further observed that the total soluble solids in the juice of 'Nagpur' orange did not change much either with increase in storage temperature or with the advancement of storage duration. The acid content was, therefore, the sole determining factor for T.S.S./Acid ratio in this variety.

In short, the progressive changes in titratable acidity and ascorbic acid content of the juice during storage were the only factors deserving special consideration to appraise the optimum storage temperature and the maximum storage life of 'Nagpur' orange.

Figure 7 clearly shows that at 35°-38°F the ascorbic acid continued to fall progressively up to six weeks but the residual content was still more than 25 kg/100 ml of juice. The T.S.S./Acid ratio was also not materially different from its original value of 25. In the following fortnight, however, sudden changes occurred in both these characters and the curves representing them crossed each other. The point of intersection at about seven weeks indicated the maximum storage life of 'Nagpur' orange at this temperature range.

The next higher storage temperature of 39°-42°F proved to be the most congenial for the storage of 'Nagpur' orange of the main-season crop. The intersection of curves for ascorbic acid and T.S.S./Acid ratio occurred as late as after 11 weeks of storage. Even

thereafter the degree of divergance between these two curves was not very great indicating that the fruit could safely be stored up to 14 weeks at this temperature. This finding was further corroborated by the low wastage of 8 per cent recorded for this temperature even after 14 weeks' storage.

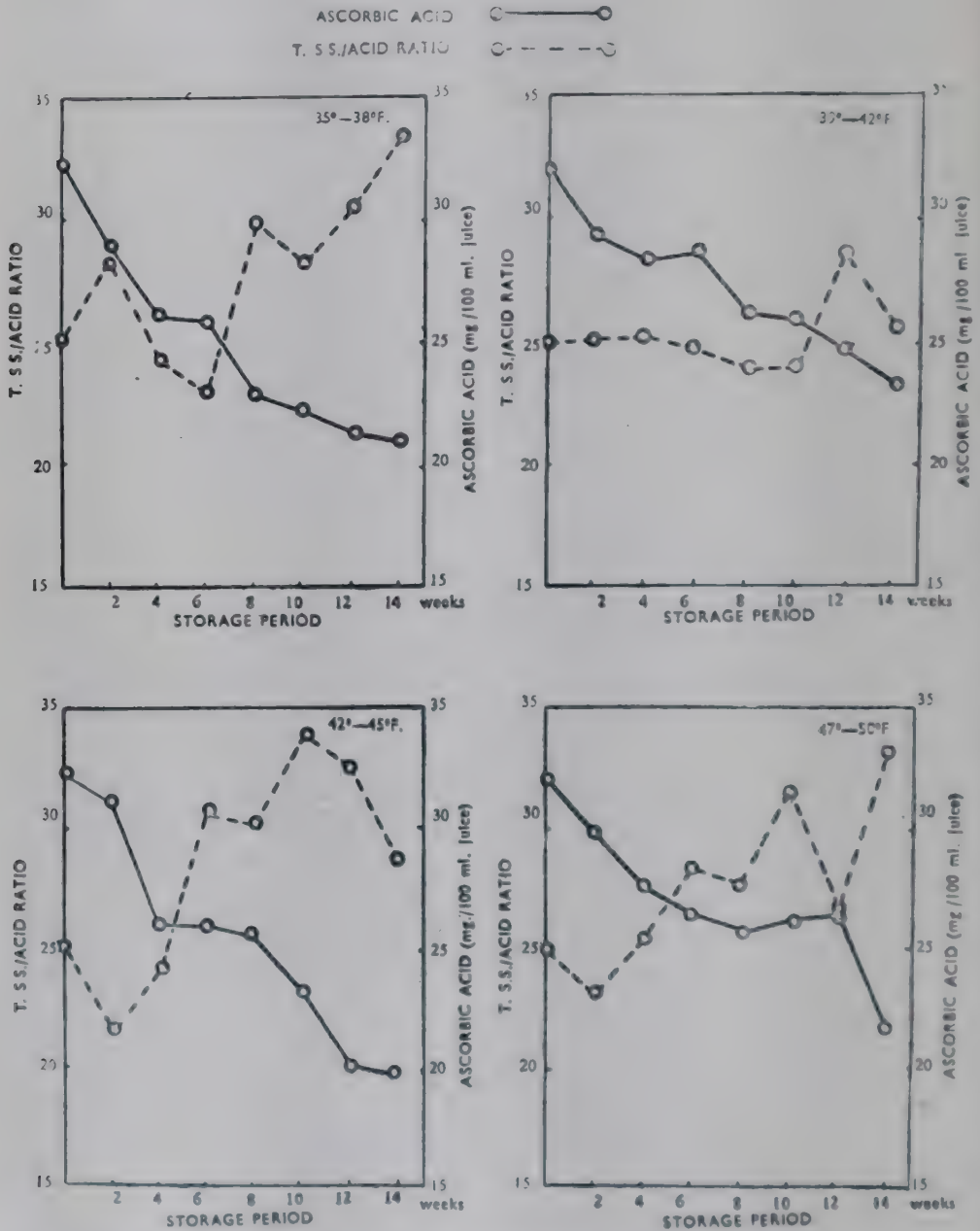


Fig. 7. Changes in the total soluble solids/acid ratio and ascorbic acid content in the juice of 'Nagpur' mandarin orange (main-season crop) during storage at different temperatures.

On similar criteria, the optimum storage life of 'Nagpur' orange of the main-season crop worked out to about five weeks at 42°-45°F and eight weeks at 47°-50°F. At these temperatures the ascorbic acid content was high enough, but the low T.S.S./Acid ratio acted as a limiting factor for further storage.

WASTAGE OF FRUIT

Coorg Mandarin' Orange

Main-season crop. The progressive wastage of fruit at different cold-storage temperatures employed is given in Table 23. The data clearly show that, up to a period of 12 weeks, the maximum wastage noted was only 8 per cent. Thus, the arbitrary limit of 10 per cent wastage fixed for economical storage was not exceeded at any storage temperature. For the storage of 'Coorg' orange fruit of the main-season crop the factor of wastage percentage did not present a serious problem. On the other hand, the physico-chemical changes, occurring in the fruit itself, turned out to be the major controlling factors.

Table 23. WASTAGE IN 'COORG' MANDARIN ORANGES DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Percentage of fruit wastage after						
	2	4	6	8	10	12	14 weeks
Main-season crop							
35°-38°F	0	0	0	0	1	8	61
39°-42°F	0	1	1	1	1	4	12
42°-45°F	0	1	1	3	3	7	24
47°-50°F	0	0	1	1	1	3	8
Rainy-season crop							
35°-38°F	0	2	6	22	34		
39°-42°F	0	10	14	18	26		
42°-45°F	2	16	32	34	50		
47°-50°F	2	16	24	32	52		

Rainy-season crop. The maximum storage life of six weeks was recorded under the lowest storage temperature of 35°-38°F (Table 23). At the next higher storage temperature (39°-42°F), the storage life was limited to four weeks. There was nothing to choose between the two highest storage temperature ranges employed, as in either case, the 'Coorg' orange of rainy-season crop could not be stored much beyond two weeks. There was a rapid disintegration of fruit

of the rainy-season crop owing to the inroad of fungal pathogens. For optimum storage life as delineated by 10 per cent critical wastage, therefore, the physico-chemical changes as discussed earlier were not of much consequence.

The relative importance of these two factors, namely the extent of fruit wastage and the loss of flavour, in determining the storage life of fruit was quite the reverse in main-season crop.

'Nagpur' Mandarin Orange

Main-season crop. Wastage of fruit in 'Nagpur' orange of the main-season crop during storage was nearly of the same order up to ten weeks under the various storage temperatures employed (Table 24). A fortnight later as high as 13 per cent wastage was recorded at the lowest temperature range of 35°-38°F, whereas in other three temperatures the value remained well within 10 per cent.

Wastage of fruit may be attributed to the attack of fungal pathogens except at 35°-38°F where the low temperature injury was also found to be responsible for causing considerable losses after 12 weeks. The development of dull appearance and subsequent browning of fruit at low temperature rendered it unmarketable.

Rainy-season crop. The storage life of 'Nagpur' orange of the rainy-season crop could be stated to be eight weeks at 35°-38°F, six weeks at the two intermediate temperature ranges and only four weeks at the highest storage temperature of 47°-50°F (Table 24). But this statement must be reconsidered in the light of observations

Table 24. WASTAGE OF 'NAGPUR' MANDARIN ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Percentage of fruit wastage after						
	2	4	6	8	10	12	14 weeks
Main-season crop							
35°-38°F	0	0	0	2	4	13	17
39°-42°F	0	0	0	3	6	7	8
42°-45°F	0	0	1	3	6	9	12
47°-50°F	0	0	4	4	5	6	10
Rainy-season crop							
35°-38°F	0	2	2	5	20		
39°-42°F	1	3	10	14	36		
42°-45°F	1	5	11	15	45		
47°-50°F	3	8	16	38	55		

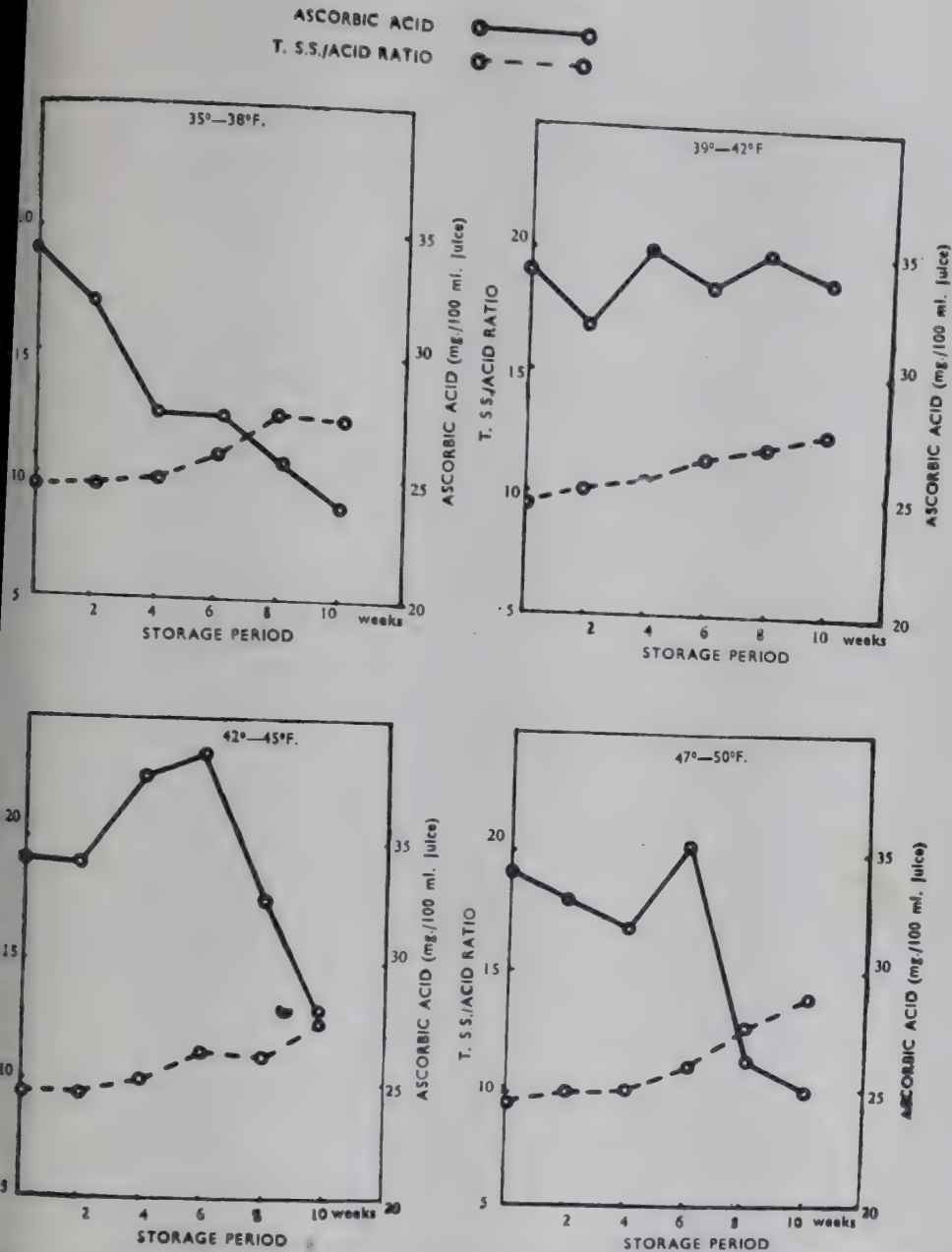


Fig. 8. Changes in the total soluble solids/acid ratio and ascorbic acid content in the juice of 'Nagpur' orange (rainy-season crop) during storage at different temperatures.

made earlier on different constituents of fruit quality especially the T.S.S./Acid ratio representing the organoleptic acceptability and ascorbic acid representing the most important protective element of this fruit. The rapid loss of ascorbic acid content at 35°-38°F would not make it desirable to extend storage at this temperature beyond six

weeks despite a low wastage of 5 per cent recorded even a fortnight later (Fig. 8). On the other hand, the remarkable preservation of quality characters at 39°-42°F would suggest the extension of storage in this case to eight weeks disregarding a high wastage of 14 per cent. There are possibilities of reducing this wastage at the optimum temperature by the adoption of additional protective measures.

'Sathgudi' Sweet Orange

The 'Sathgudi' Sweet Orange kept extremely well for 12 weeks at all the storage temperatures (Table 25). There was practically no wastage except at the highest storage temperature of 47°-50°F registering a total wastage of 6 per cent by this time. With further storage up to 14 weeks fruits at 35°-38°F registered 8 per cent wastage which rapidly progressed to 27 per cent at the end of 20 weeks. The high rate of wastage at this temperature range was largely owing to the collapse of fruit with low temperature injury. The wastage was comparatively much less at the next higher storage temperature of 39°-42°F but the temperature range of 42°-45°F proved to be most congenial registering the lowest loss of 7 per cent even after 20 weeks. It is noteworthy that the highest storage temperature of 47°-50°F which was leading in wastage up to 12 weeks subsequently proved less deleterious and caused a total wastage of only 13 per cent.

Table 25. WASTAGE IN 'SATHGUDI' SWEET ORANGE DURING STORAGE AT DIFFERENT TEMPERATURES

Storage period weeks	Percentage of fruit wastage at			
	35°-38°F	39°-42°F	42°-45°F	47°-50°F
2	0	0	0	0
4	0	0	0	1
6	0	0	0	2
8	0	0	0	2
10	0	0	1	4
12	0	1	1	6
14	8	6	3	6
16	14	7	4	8
18	22	9	4	11
20	27	12	7	13

During the early storage period of 12 weeks, about 15 to 20 per cent of fruit at 35°-38°F showed shrivelling. There was no marked

change in colour but low temperature injury was visible on certain shrivelled fruits. At 39° - 42° F, the condition of fruit was very similar to the fruit at 35° - 38° F, whereas shrivelling and low temperature injury were less acutely marked. A slight favourable change in rind colour was noticeable. Fruit at the next higher storage temperature of 42° - 45° F, however, developed good yellow colour during 12 weeks' storage without showing any signs of shrivelling. Colour development was still better at 47° - 50° F and appearance more attractive.

Storage beyond 12 weeks brought about no colour improvement in the fruit kept at 35° - 38° F. A slight favourable change was noticeable at 39° - 42° F after 14 weeks which continued thereafter but did not result in the development of full orange colour even after 20 weeks' storage. At 42° - 45° F, the fruit developed attractive yellow colour which deepened to fair orange on further storage. The storage temperature of 47° - 50° F had the most salutary effect on colour change. Yellow orange colour appearing by the end of 14 weeks turned to deep orange subsequently. It must be remembered that intense colouration at the highest storage temperature of 47° - 50° F was rather deceptive as the fruit had become almost non-juicy from within with prolonged storage.

The wastage of fruit at different storage temperature was different in kind and intensity. At 35° - 38° F, storage spot was the commonest type of injury resulting in collapse of fruit and appearance of fawn or brown colouration of the rind. Fungal growth occurred late during storage on the collapsed fruit. At 39° - 42° F, there was still some low temperature injury but fungal growth was also common. The remaining two higher storage temperatures caused no chilling injury and the wastage of fruit was largely owing to the attack of green and blue moulds. The green mould was found to be more common on the 'Sathgudi' orange and usually overspread the blue mould. Stem-end rot was particularly noticeable at the highest temperature range of 47° - 50° F with prolonged storage.

BEHAVIOUR OF FRUIT AT ROOM TEMPERATURE

To get an idea of the changes that occur in the fruit in the absence of refrigeration facilities, an additional lot of 'Coorg' Mandarin Oranges was kept in the laboratory under the prevailing atmospheric conditions at Mysore. The room temperature during these studies ranged from 76° - 90° F and the relative humidity from 37 to 62 per cent. A complete record of the various physico-chemical changes in fruit occurring under these storage conditions was maintained and the results are summarised in Table 26.

The loss in fruit weight amounted to 13.2 per cent at the end of the first fortnight of storage at room temperature. This was many times higher than the corresponding mean loss of 1.8 per cent at the cold storage temperature. With storage up to eight weeks at room temperature, the loss went up to 47.9 per cent of its original fresh weight. The fortnightly loss varies from 10.1 to 13.2 per cent. By this time the cold-stored fruit had suffered a gross loss of 7.9 per cent only. Evidently, at room temperature, the fruit suffered heavy and rapid losses.

The peel portion also exhibited pronounced changes at room temperature. From the initial value of 31.2 per cent, it rapidly declined to 24.4 per cent in eight weeks. On the contrary, the changes in the peel fraction under cold storage conditions were comparatively small and were to the reverse order.

The juice at room temperature also registered a marked downward trend particularly after four weeks' storage. From 47.6 per cent in the beginning the juice percentage declined to 40.3 per cent in eight weeks' time. Not only did the juice decreased but along with it even the moisture content of juice fell from 86.6 to 79.2 per cent during the same period. Consequent upon the reduction of moisture in juice,

Table 26. PHYSICO-CHEMICAL CHANGES IN 'COORG' MANDARIN ORANGE DURING STORAGE AT ROOM TEMPERATURE (76°-90° F)

Particulars	Storage period in weeks					Rainy-season	
	Main-season crop					crop	
	0	2	4	6	8	0	2
1. (a) Cumulative loss in weight of fruit (%)	—	13.2	23.3	36.3	47.9	—	20.5
(b) Fortnightly loss (%)	—	13.2	10.1	13.0	11.6	—	—
2. Peel (%)	31.2	29.1	28.2	27.2	22.4	28.9	92.5
3. Juice (%)	47.6	47.4	46.5	43.1	40.3	51.7	50.9
4. Moisture in juice (%)	86.6	85.6	83.7	81.7	79.2	91.2	89.2
5. Total soluble solids in juice (%)	13.3	14.0	15.0	18.0	20.2	9.8	10.2
6. Reducing sugars (%)	4.6	5.2	7.1	9.1	11.7	2.1	2.5
7. Acidity as anhydrous citric acid (%)	0.76	0.78	0.80	0.76	0.81	0.77	0.67
8. Ascorbic acid in juice mg/100 ml	27.6	31.7	34.3	31.4	37.1	37.5	39.4
9. T.S.S./Acid (ratio)	17.5	18.0	18.7	23.7	25.0	12.0	15.0
10. Wastage of fruit (%)	—	4.0	6.0	7.0	11.0	—	40.0

the total soluble solids increased from 13.3 to 20.2 per cent after eight weeks. The percentage of reducing sugars in the same way rose from 4.6 to 11.7 per cent. These figures amply indicate the rapidity at which the fruit kept at room temperature underwent desiccation and shrivelling.

Unlike the other juice constituents, discussed above, the acidity did not show high concentration with the prolongation of storage period, though a slight trend of increase was noticeable. The changes in ascorbic acid did not follow total acidity but fell in line with total soluble solids. The continuous increase in ascorbic acid from 27.6 to 37.1 mg/100 ml of juice during storage regardless of high room temperature and the attendant heavy moisture losses is an outstanding feature.

The T.S.S./Acid ratio rose to 18.7 in four weeks, and thereafter it showed steep rise signifying the development of insipidness in fruit.

Despite such rapid losses of moisture from fruit, as observed at room temperature, the wastage percentage was surprisingly low and reached only 11 per cent after eight weeks. High room temperature, therefore, encouraged desiccation more than the decay of fruit itself.

Reconsidering collectively the changes in the physico-chemical complex of fruit, the storage life at room temperature appears to be only two weeks by which time the fruit had lost 13.2 per cent of its fresh weight. Beyond this, the fruit assumed shrivelled look with continuous loss of moisture which lowered its acceptability in the market. It is noteworthy, however, that up to four weeks the taste of fruit as represented by the T.S.S./Acid ratio of 18.7, was favourable and it was accompanied by high ascorbic acid value of 34.3 mg/100 ml of juice and low wastage rate of 6.0 per cent. Hence the fruit, though excessively shrivelled after four weeks' storage, was still nutritious and palatable.

V. EFFECT OF STORAGE TEMPERATURE ON COLOUR DEVELOPMENT IN 'SATHGUDI' SWEET ORANGE

The tropical conditions prevailing in Andhra Pradesh, where 'Sathgudi' sweet orange is extensively grown, are not conducive to the proper development of orange colour on fruit. On maturity the fruit maintains various shades of green hue in combination with yellow. Since the orange is particularly prized for its attractive orange colour apart from its nutritive value, the improper colour development would substantially detract its market value.

During current investigations, the rate and intensity of colour development were observed to be associated with storage temperature employed. The higher storage temperatures were invariably attended by better colour development. As the highest range of storage temperature employed was only 47°-50°F, it was considered worthwhile to go still higher up to the temperature range of 52°-55°F and study its beneficial effect on the development of orange colour.

In this experiment, therefore, four temperature ranges, viz. 39°-42°F, 42°-45°F, 47°-50°F and 52°-55°F were employed. Fortnightly observations were recorded on the extent of colour development of the rind in arbitrary colour grades and the results are summarised in Table 27.

Table 27. COLOUR DEVELOPMENT IN 'SATHGUDI' SWEET ORANGE AS OBSERVED AT FORTNIGHTLY INTERVALS DURING STORAGE AT DIFFERENT TEMPERATURES

Storage period	39°-42°F	42°-45°F	47°-50°F	52°-55°F
0 week (s)	Pale green	Pale green	Pale green	Pale green
2 "	Pale green	Yellowish green	Light yellow	Good yellow
4 "	Pale green	Light yellow	Fair yellow	Fair orange
6 "	Pale green	Light yellow	Good yellow	Good orange
8 "	Pale green	Fair yellow	Full yellow	Good orange
10 "	Pale green	Good yellow	Deep yellow	Full orange
12 "	Light yellow	Good yellow	Light orange	Deep orange

Little change in the colour of fruit was noticeable up to ten weeks at the lowest temperature range of 39°-42°F where it continued to look pale green. After that the fruit turned light yellow.

The next storage temperature of 42°-45°F favoured the development of yellow colour but the intensification of this hue was rather slow. The colour grade gradually changed from the initial pale green to good yellow at the end of 12 weeks. The fruit failed to attain full yellow colour during this period.

Storage at 47°-50°F was quite conducive to the rapid intensification of yellow hue which became deep yellow in ten weeks. The colour further changed to light orange in the following fortnight.

At 52°-55°F, the change from pale green to good yellow was fast and led to the appearance of fair orange colour with storage of only four weeks. Further storage up to 12 weeks helped to deepen this hue. It is remarkable that storage at 52°-55°F favoured the development of the characteristic orange colour right away instead of the deepening of yellow hue over long period as was noted at the lower storage temperature range of 47°-50°F.

To have a quantitative idea of colour development detailed observations were made at three stages, viz. (1) at the beginning of storage studies, (2) after twelve weeks of storage, and (3) at the end of the storage period of twenty weeks. The units of various constituent colours, namely yellow (Y), red (R) and blue (B) were determined with the aid of B.D.H. Lovibond Tintometer. The composite hue was described after the Horticultural Colour Chart of Wilson (1938). Since the fruit is seldom uniformly coloured during early stages of storage, attempt was made to represent the colour gradient by recording observations from two spots on the rind representing the extremes of colour shade present on the fruit (Table 28).

On the commencement of storage, 'Sathgudi' orange looked sap green to primrose yellow (according to the Horticultural Colour Chart). Storage of fruit at 39°-42°F for a period of 12 weeks turned the fruit lemon yellow to straw yellow due to the disappearance of the blue component and greater manifestation of the yellow and red components. Further storage up to 29 weeks did not bring about any significant change in colour. There was only a slight increase in the red component modifying the straw yellow colour to buttercup yellow.

At 42°-45°F, the colour of fruit changed from the initial sap green to buttercup yellow in 12 weeks. After 20 weeks of storage the yellow hue further deepened into Indian yellow on account of simultaneous increase in colour units of yellow and red.

Twelve weeks' storage at 47°-50°F led to the development of cadmium orange colour whose chief distinguishing constituent was the red component with values ranging from 5.0 units as measured by the Lovibond Tintometer. After 20 weeks the fruit at this temperature developed deeper shade of tangerine orange which was largely

owing to the increase of red units. There was a minor increase in yellow units also.

Table 28. COLOUR DEVELOPMENT IN 'SATHGUDI' SWEET ORANGE AFTER 12 AND 20 WEEKS' STORAGE AT DIFFERENT TEMPERATURES

Storage temperature	Initial			After 12 weeks			After 20 weeks		
	Y*	R*	B*	Y	R	B	Y	R	B
39°-42°F	13.0	0.7	1.9	20.0	2.9	0.0	20.0	2.9	0.0
	(Sap green 62/1)			(Lemon yellow 4/1)			(Lemon yellow 4/1)		
	TO			TO			TO		
42°-45°F	15.0	1.0	0.0	20.0	3.0	0.0	20.0	3.2	0.0
	(Primrose yellow 601)			(Straw yellow 604)			(Buttercup yellow 5/1)		
	TO			TO			TO		
47°-50°F	13.0	0.7	1.9	20.0	3.2	0.0	20.0	3.5	0.0
	(Sap green 62/1)			(Buttercup yellow 5/1)			(Buttercup yellow 5/2)		
	TO			TO			TO		
52°-55°F	15.0	1.0	0.0	20.0	3.3	0.0	20.8	4.0	0.0
	(Primrose yellow 601)			(Buttercup yellow 5/2)			(Indian yellow 6)		
	TO			TO			TO		
47°-50°F	13.0	0.7	1.9	20.0	5.0	0.0	20.2	4.9	0.0
	(Sap green 62/1)			(Cadmium orange 8)			(Cadmium orange 8)		
	TO			TO			TO		
52°-55°F	15.0	1.0	0.0	20.0	5.4	0.0	20.1	6.0	0.0
	(Primrose yellow 601)			(Cadmium orange 8)			(Tangerine orange 9)		
	TO			TO			TO		
52°-55°F	13.0	0.7	1.9	20.1	6.0	0.0	20.0	6.0	0.0
	(Sap green 62/1)			(Tangerine orange 9)			(Marigold orange 11)		
	TO			TO			TO		
52°-55°F	15.0	1.0	0.0	20.0	6.8	0.0	20.0	7.9	0.0
	(Primrose yellow 601)			(Tangerine orange 9)			(Orange 12/1)		
	TO			TO			TO		

* Colour units of Y (yellow), R (red) and B (blue) were determined by B.D.H. Lovibond Tintometer.

The storage temperature of 52°-55°F was responsible for early development of orange colour which deepened to tangerine orange within 12 weeks. The intensification of colour continued with further storage up to 20 weeks turning marigold orange to full orange.

The foregoing account would bear out that both the storage temperature and the storage duration had profound influence on the rate and intensity of colour development in 'Sathgudi' sweet orange.

VI. OPTIMUM TEMPERATURE COMBINATION FOR STORAGE AND COLOUR DEVELOPMENT OF 'SATHGUDI' SWEET ORANGE

In the preceding chapters, it has been shown that the temperature range of 42°-45°F was most favourable for the development of orange colour in 'Sathgudi' sweet orange. The appearance of attractive orange colour at 52°-55°F was noted as early as four weeks after storage. It was, therefore, decided to try these two temperature ranges in suitable combinations to obtain best results in storage studies. In one temperature combination treatment the fruit was kept initially for four weeks at 52°-55°F and was subsequently transferred to 42°-45°F for the remaining storage period of 16 weeks. In the second temperature combination treatment the spell of four weeks at 52°-55°F was increased to six weeks and provided after the initial storage of 14 weeks at 42°-45°F. The scheme of temperature combinations and their duration was thus as under:

Temperature combination	Initial temperature		Succeeding temperature	
	Range	Duration	Range	Duration
A	82°-55°F	4 weeks	42°-45°F	16 weeks
B	42°-45°F	14 weeks	52°-55°F	6 weeks

In the second temperature combination the initial storage at 42°-45°F was purposely decreased from 16 to 14 weeks to introduce the higher storage temperature of 52°-55°F at a favourable physiological state of fruit to ensure proper colour development of fruit and its disposal without incurring serious losses due to wastage.

(i) *Storage behaviour of fruit.* The results of periodic determinations on loss in fruit weight, progressive wastage of fruit, peel percentage and juice content of fruit under the two temperature combinations over the 20-week-storage period are given in Table 29.

Temperature combination 'A' which involved initial holding of fruit for four weeks at 52°-55°F caused slightly greater losses in fruit weight and total wastage during this initial period as compared with the temperature combination 'B'. The rate of loss in weight continued to be comparatively higher at temperature combination 'A' up to 12 weeks despite the transfer of this fruit after four weeks. After 14 weeks of storage the effect of these two temperature combinations on the loss in weight and number of fruit became almost the same. Subsequently, however, the losses in respect of both these

characters mounted high more particularly in the case of temperature combination 'B' as during this period the fruit under this treatment became subject to the second complement of higher temperature range of 52°-55°F. The ultimate loss in fruit weight after 20 weeks was 16.1 and 21.6 per cent for the temperature combinations 'A' and 'B' respectively. The corresponding values of total wastage of fruit were 16 and 24 per cent.

Table 29. PERIODIC LOSSES IN WEIGHT, FRUIT WASTAGE, AND CHANGES IN PEEL AND JUICE CONTENT OF 'SATHGUDI' SWEET ORANGE DURING STORAGE UNDER DIFFERENT TEMPERATURE COMBINATIONS

Storage period	Loss in wt %		Wastage %		Peel %		Juice %	
	Temp. A*	Temp. B**	Temp. A	Temp. B	Temp. A	Temp. B	Temp. A	Temp. B
0 week(s)	—	—	—	—	25.7	25.4	54.6	53.7
2 „	3.0	1.6	0	0	30.5	31.9	49.3	51.2
4 „	5.0	3.9	2	0	30.8	29.3	50.0	49.3
6 „	6.5	4.9	2	0	29.0	31.8	49.8	49.3
8 „	7.9	6.6	2	0	34.4	28.7	44.6	44.7
10 „	9.2	8.1	2	2	30.8	33.2	47.9	46.4
12 „	10.6	10.2	4	6	33.6	34.9	45.5	42.9
14 „	11.8	12.0	4	6	35.7	32.8	43.3	43.1
16 „	13.0	15.4	8	10	33.3	33.1	41.2	41.8
18 „	14.6	19.2	10	16	34.4	36.6	40.4	39.0
20 „	16.1	21.6	16	24	32.9	35.9	41.5	38.4

* Temp. A: 52°-55°F for four weeks followed by 42°-45°F for 16 weeks.

** Temp. B: 42°-45°F for 14 weeks followed by 52°-55°F for six weeks.

The temperature combinations showed little differential effect on the peel and juice content of fruit up to 14 weeks of storage. The introduction of higher temperature at this stage in the case of temperature combination 'B' gradually increased the peel percentage and decreased the juice content as compared with temperature combination 'A'. These effects became visible four weeks after the transfer of fruit to higher temperature. The final values of peel percentage for the temperature combinations 'A' and 'B' after 20 weeks' storage were 32.9 and 35.9 per cent, and for juice were 41.5 per cent respectively.

The quantitative determinations on periodic changes in total soluble solids, titratable acidity, T.S.S./Acid ratio and ascorbic acid in the juice of 'Sathgudi' orange under the two temperature combinations are set out in Table 30.

Little effect of temperature treatment was visible on the total soluble solids of juice up to 16 weeks of storage after which a slight upward trend was noted under temperature combination 'B'. Adverse effect of temperature combination 'B' on the titratable acidity of juice also became visible at about the same time. Hence, the sugar/acid blend as presented by T.S.S./Acid ratio deteriorated abruptly in this case beyond 16 weeks.

Table 30. PERIODIC CHANGES IN TOTAL SOLUBLE SOLIDS, TITRATABLE ACIDITY, T.S.S./ACID RATIO AND ASCORBIC ACID CONTENT IN THE JUICE OF 'SATHGUDI' SWEET ORANGE DURING STORAGE UNDER DIFFERENT TEMPERATURE COMBINATIONS

Storage period	T.S.S. %		Acidity %		T.S.S./Acid ratio		Ascorbic acid mg/100 ml juice	
	Temp.		Temp.		Temp.		Temp.	
	A*	B**	A	B	A	B	A	B
0 weeks(s)	12.3	11.8	0.53	0.51	23.2	23.1	58.8	59.7
2 "	12.5	12.5	0.51	0.50	24.5	25.0	59.8	53.8
4 "	12.7	12.6	0.49	0.51	25.9	24.7	57.7	54.5
6 "	12.9	13.1	0.53	0.54	24.3	24.2	59.5	47.4
8 "	12.6	12.4	0.51	0.50	24.7	24.8	48.3	46.7
10 "	12.8	13.2	0.48	0.49	26.6	26.9	55.4	49.2
12 "	13.2	14.0	0.52	0.53	25.3	26.4	47.8	51.4
14 "	12.4	13.8	0.46	0.51	26.9	27.0	51.7	56.9
16 "	13.5	13.4	0.47	0.49	28.7	27.4	52.6	49.0
18 "	13.7	14.0	0.43	0.31	31.8	45.1	46.5	34.2
20 "	14.0	15.0	0.45	0.30	31.1	50.0	43.7	32.8

* Temp. A: 52°-55°F for four weeks followed by 42°-45°F for 16 weeks.

** Temp. B: 42°-45°F for 14 weeks followed by 52°-55°F for six weeks.

As compared with these constituents of fruit juice, the ascorbic acid content showed an altogether different behaviour. In temperature combination 'A', the higher temperature complement during the initial storage period of four weeks helped to maintain consistently a higher concentration of ascorbic acid up to eight weeks as compared with the temperature 'B'. On the other hand, the introduction of higher temperature after 14 weeks in temperature combination 'B' caused rapid destruction and disappearance of ascorbic acid. The final values of ascorbic acid after 20 weeks for temperature combination 'A' and temperature combination 'B' were 43.7 and 32.8 mg/100 ml of juice respectively.

(ii) *Colour development.* In temperature combination 'A' the initial holding of fruit at 52°-55°F for four weeks favoured the development of fair orange colour. Subsequent transfer of this fruit

to the lower temperature range of 42°-45°F slowed down further deepening of this hue. The net result was that after 20 weeks of storage the fruit under temperature combination 'A' developed cadmium orange to tangerine orange. This was quite an attractive orange shade but was much less intense as compared with marigold orange or full orange colour developed when the fruit was kept throughout at 52°-55°F as already reported under the preceding experiment on colour development.

Under temperature combination 'B' the fruit turned only light yellow after four weeks while it was held at 42°-45°F. Even with 14 weeks' storage at this temperature, before its transfer to the higher temperature complement of 52°-55°F, the fruit had attained only full yellow or Indian yellow colour. After transfer to the higher temperature in this treatment the fruit developed saffron yellow to cadmium orange colour at the end of 20 weeks' storage.

Out of these two temperature combination treatments, the temperature combination 'A' which comprised early holding of fruit at 52°-55°F for four weeks and subsequent storage at 42°-45°F for the rest of the storage period proved to be physiologically more desirable and economically more sound than temperature combination 'B'.

VII. EFFECT OF FRUIT SIZE ON KEEPING QUALITY OF 'COORG' MANDARIN AND 'SATHGUDI' SWEET ORANGE

A. LOSS IN WEIGHT OF FRUIT

'Coorg' Mandarin Orange. Investigations were conducted on the fruit of the main-season as well as of the rainy-season crop. The cold storage temperature employed was 39°-42°F which was found to be the optimum in the preceding experiment.

The fruit size designated as 'large', 'medium', and 'small' subsequently differed from one another (Table 31). Approximately, the 'small' fruit was just one-half of the 'large' fruit in weight.

Table 31. EFFECT OF FRUIT SIZE ON LOSS IN THE WEIGHT OF 'COORG' MANDARIN ORANGE (CUMULATIVE LOSS %) DURING STORAGE AT 39°-42°F

Fruit size	Original fresh wt per fruit (g)	Storage period in weeks						
		2	4	6	8	10	12	14
Main-season crop								
Large	163.9	2.0	4.2	5.8	7.4	9.8	12.1	14.3
Medium	122.0	2.4	4.4	6.3	7.8	10.1	12.5	14.8
Small	89.0	2.5	4.7	6.5	8.1	10.2	12.9	15.2
Rainy-season crop								
Large	161.8	3.9	7.6	12.0	17.1	21.3		
Medium	114.4	5.0	11.5	15.0	20.8	26.0		
Small	84.5	6.2	13.0	18.5	25.2	30.6		

Even with wide variation in fruit size, the rate of loss in fruit weight of the main-season crop (Table 31) was not significantly influenced during storage at 39°-42°F. This was true whether the loss was considered on cumulative basis or on actual fortnightly basis. A feeble trend of higher loss in small fruit could, however, be noted. The total loss during 14 weeks' storage for 'large', 'medium' and 'small' fruit was 14.3, 14.8 and 15.2 per cent respectively. The corresponding values of average fortnightly loss for the three fruit size worked out to 2.04, 2.11 and 2.17 per cent.

But in the case of rainy-season crop (Table 31) fruit size exhibited considerable effect on the rate of loss in fruit weight. Cumulative losses amounting to 31.2, 26.0 and 30.6 per cent were recorded for the 'large', 'medium' and 'small' fruits respectively after storage for ten weeks at 39°-42°F. These results when expressed as 'fortnightly loss' and analysed statistically were again confirmed. The average

fortnightly loss for the three fruit sizes was 4.26, 5.20 and 6.12 per cent. The association of higher loss in fruit weight with smaller fruit size became visible right from the first fortnight of storage and persisted throughout the storage period of ten weeks.

'Sathgudi' Sweet Orange. For this experiment, the fruit was sorted into two size grades. The large size had a diameter of 7.5 cm and the medium size 7 cm. The cold storage behaviour of these two grades was studied at 39°-42°F and 42°-45°F for 20 weeks and fortnightly data were recorded on (i) loss in weight of fruit and (ii) the wastage of fruit itself. The average fortnightly loss for the large fruit worked out to 2.11 per cent which was significantly lower than the loss of 2.34 per cent recorded for the medium-sized fruit. It could be attributed to the comparatively large surface area exposed per unit weight by the medium-sized fruit.

The storage temperatures of 39°-42°F and 42°-45°F did not show materially different effects on the rate of loss in fruit weight, though the higher temperature did register a slightly higher loss. The average rate of loss at 39°-42°F was 2.20 per cent as against 2.25 per cent at 42°-45°F.

The effect of storage duration on weight loss was almost identical under all treatment combinations exhibiting progressively higher rate of loss with prolonged storage period. At any stage during storage, the actual value of loss in weight represented the comparative treatment effects almost free from interaction with storage duration.

B. WASTAGE OF FRUIT

'Coorg' Mandarin Orange. Fruit size had no particular effect on the wastage of 'Coorg' orange of the main-season crop (Table 32). The ultimate wastage in 'large', 'medium' and 'small' fruits after fourteen weeks' storage was 15, 14 and 17 per cent respectively.

Table 32. EFFECT OF FRUIT SIZE ON THE WASTAGE OF 'COORG' MANDARIN ORANGE OR 'MAIN' AND 'RAINY' SEASON CROPS DURING STORAGE AT 39°-42°F

Crop	Fruit size	Percentage of fruit wastage after						
		2	4	6	8	10	12	14 weeks
Main season	Large	0	0	0	0	2	4	15
	Medium	0	0	0	1	3	5	14
	Small	0	0	0	1	4	5	17
Rainy season	Large	0	0	4	12	26		
	Medium	0	3	10	18	34		
	Small	0	2	4	16	33		

In the case of rainy-season crop, however, medium and small fruit suffered greater loss than the large fruit. The relative differences showed up after eight weeks' storage.

The seasonal effect was more patent. The fruit of the rainy-season crop succumbed early to mould attack and piled up heavier losses in a shorter time as compared with the fruit of the main-season crop. After ten weeks' storage nearly one-third of the rainy-season fruit was destroyed.

'Sathgudi' Sweet Orange. The 'large' fruit with an average diameter of 7.5 cm proved to be a better keeper than the 'medium' sized fruit of 7 cm irrespective of the storage temperature. Of the two storage temperatures employed, the higher range 42°-45°F proved to be more favourable as it registered losses of only 4 and 7 per cent for the large and medium-sized fruits respectively after 20 weeks' storage. The corresponding losses at 39°-42°F for these two grades of fruit were 9 and 12 per cent.

The findings on optimum storage temperature are in conformity with those reported under the experiment on 'Optimum Storage Temperature for Sathgudi Orange' where the temperature range of 42°-45°F was revealed to be the best one. The interaction effect of fruit size with storage temperature was completely absent.

VIII. EFFECT OF METHOD OF PICKING ON THE STORAGE LIFE OF 'COORG' MANDARIN ORANGE

'Coorg' orange fruit of the main-season crop was picked in two different ways, viz. (i) pulling off the fruit by hand, and (ii) clipping the fruit along with a small stem-end piece by means of clippers. The fruit thus picked was stored under three cold-storage temperatures to determine the effect of picking practices on the storage life of fruit. Observations were recorded on periodic losses in the weight of fruit and on wastage percentage. The results are summarized below.

(i) *Loss in weight of fruit.* Cumulative losses in fruit weight after 14 weeks' storage showed that clipping was slightly advantageous over pulling. The former practice registered a mean loss of 14.9 per cent against 15.7 per cent by the latter when averaged over the three storage temperatures employed. The advantage of clipping over pulling was thus small. A difference of 1.0 per cent only was recorded under the highest storage temperature range of 42°-45°F, where the total losses for the two practices were 16.3 and 17.3 per cent respectively.

When the absolute loss in fruit weight was reassessed as fortnightly rate of loss, the above observations were again confirmed by an average loss of 2.13 per cent with clipping as against 2.24 per cent with pulling. Although the difference between these two mean values bordered on statistical significance, quantitatively it was too small to be of any consequence.

Over the range of temperature employed, the higher storage temperatures were attended by greater losses regardless of the method of picking.

(ii) *Wastage of fruit.* Observations made on the progressive wastage of fruit during storage reflected significant differences in the treatment effect of clipping versus pulling after 14 weeks' storage. But considering the storage temperatures individually it was seen that greater wastage under pulling occurred only at the two higher storage temperatures of 39°-42°F. When these findings were viewed further in conjunction with the optimum storage life of 10 to 12 weeks for this variety it was found that during this optimum period there was little difference in the total wastage of fruit picked in these two ways. Even judged by the arbitrary limit of 10 per cent wastage for economical storage of fruit, it would be seen that in no case was this limit exceeded up to 12 weeks. The method of picking, therefore, did not play any significant role in determining the storage life of 'Coorg' orange.

X. EFFECT OF ORCHARD VARIABILITY ON THE COLD STORAGE BEHAVIOUR OF 'COORG' MANDARIN ORANGE

The 'Coorg' orange derives its name from the Coorg State where it is commonly grown. Within Coorg itself the cultivation of this fruit is confined mainly to the sharply defined eastern belt of dark-brownish clayey soil. Coorg also contains extensive areas of red loam and laterite soils progressively extending towards the west. The three well-defined soil types of Coorg region have emerged under the impact of local climatic factors operating over centuries. Of these, the eastern part is more favoured with well-distributed rainfall, luxuriant forest vegetation and the resulting well-drained dark-brown clayey soils rich in humus. This agro-climatic complex makes the eastern belt of Coorg State ideally suited for the cultivation of mandarin orange. Even within this belt mandarin groves are found to be concentrated in certain localities of the north and south. Out of the two, the southern part is more important for orange production.

(i) *Description of orchards.* For the purpose of these investigations four important orange-growing localities were selected, namely Tithimati and Pollibetta in South Coorg and Somvarpet and Shanivarsante in North Coorg. In view of the greater concentration of orange plantations in South Coorg, three orchards in close vicinity of each of the Tithimati and Pollibetta localities were earmarked to study more

Table 33. DESCRIPTIVE DETAILS OF ORCHARDS INCLUDED FOR STUDIES ON ORCHARD VARIABILITY

Locality and name of orchard	Altitude (m)	Cultural practices and other remarks
TITHIMATI		
Balmany Estate	833	18-year-old trees with good bearing capacity. Bumper crop during the year of study. Manuring for the last three years at the annual rate of 2.7 kg of ammonium sulphate per tree in two split doses, viz. 1.3 kg in May (pre-monsoon season) and 1.3 kg in September (post-monsoon season). Spraying with Bordeaux mixture (4:4:40) during September after the monsoon rains each year.
B & C Estate	830	16-year-old trees with good bearing capacity. Normal crop during the year under study.

		<p>Manuring regulate with farmyard manure at 13.6 kg per tree and ammonium sulphate at 1.8 kg per tree a year. Green manuring with <i>Crotalaria</i>.</p> <p>Spraying twice a year with Bordeaux mixture (4:4:40).</p> <p>Remarks : Green gram sown in May and cut down in July.</p>
Bhadragola Estate	826	<p>13-year-old trees, good crop with heavy yield during the year of study.</p> <p>Manured all along with farm manure at the rate of 13.5 kg per tree once a year in May.</p> <p>No spraying practised.</p> <p>Remarks : Drought conditions prevailed during fruit ripening in the year under study.</p>
POLLIBETTA Craigmore Estate	981	<p>14-year-old trees, bearing capacity consistently fair.</p> <p>Manuring : None</p> <p>Spraying : None</p>
Muscalbora Estate	945	<p>18-year-old trees, normally fair cropper but bore thin crop during the year of study.</p> <p>Manuring for the last three years at the rate of 2.7 kg of ammonium sulphate per tree every year in June.</p> <p>Spraying with Bordeaux mixture (4:4:40) once a year in May before rains.</p> <p>Remarks : The fruit of this orchard is reputed for sweetness.</p>
Yemmigoondi Estate	975	<p>14-year-old trees, regular and bearing capacity heavy.</p> <p>Manuring for the last two years at the rate of 1.8 kg bone-meal in February +1.8 kg ammonium sulphate in March +1.8 kg ammonium sulphate in September per tree.</p> <p>Spraying with Bordeaux mixture (4:4:40) once a year.</p>
SOMVARPET Chinnali Estate	1130	<p>18-year-old tree, bearing regular and heavy with good crop during the year under study.</p> <p>Manuring for the last 8 years at the rate of 0.45 kg ammonium sulphate in January +27.2 kg of jungle soil rich in humus</p>

during February +27.2 kg of farmyard manure in September.

Spraying : None. No disease.

SHANIVARSANTE

Huntsey Estate	966	18-year-old trees, bearing regular and heavy with bumper crop during the year of study.
		Manuring for the past many years with ammonium sulphate at the rate of 4.5 kg per tree in two split doses, one-half in May (pre-monsoon) and the second half in September (post-monsoon).
		Spraying with Bordeaux mixture (4:4:40) once a year.
		Remarks : The fruit of this orchard is discounted for its poor keeping-quality.

precisely the component of orchard variability arising from factors other than soil and climate, which are bound to be confound in distantly located centres. Information on individual orchards regarding their cultural practices and distinctive features is given in Table 33.

Fruit collected from these orchards was stored at 39°-42°F, which was found to be the optimum storage temperature in earlier investigations. Periodic observations on the physico-chemical changes in fruit quality were recorded and subject to the analysis of variance. Orchards showed highly significant differences in all the characters studied. Periods of storage also showed similar significant effects, but their consideration will be limited to the interaction effects with orchards.

(ii) *Loss in weight of fruit.* The results showed that fruit from different orchards varied widely both in respect of original fresh weight and losses sustained during storage. On the whole, the smaller fruit size was associated with lower cumulative loss in weight after 12 weeks' storage. Likewise the larger fruit size recorded higher loss. The Tithimati locality, where the original fresh weight per fruit was the lowest as a group and ranged from 126.5 g to 140.2 g, recorded cumulative loss of only 9.1 to 10.1 per cent in 12 weeks. It may be mentioned here that Tithimati has the lowest altitude of about 820 m and the lowest annual rainfall. The total precipitation at Tithimati during 1951, the year covering the crop under study, was 1.18 m as compared with 2.05 m, 1.55 m and 1.70 m for Somvarpet, Pollibetta and Shanivarsante respectively. Consequently, the Tithimati locality is comparatively drier and warmer. This seems to have influenced favourably the ripening of fruit which in turn lowered the rate of loss in its weight during storage.

Among the orchards in the Tithimati group the largest fruit size of 140.2 g was noted for the B and C Estate accompanied by the lowest loss of 9.1 per cent in fruit weight. This observation is a conspicuous deviation from the overall positive regression of weight loss on fruit size. This may be attributable to better management practices followed at this Estate than at others in this group.

The three Estates of Craigmore, Yemmigoondi and Muscalbora around Pollibetta showed significant differences in fruit size attended by similar differences in weight loss during 12 weeks. The positive relationship of fruit size with weight loss became visible at the first fortnightly interval and was maintained consistently throughout the storage period. The low values for Craigmore in this group may be a direct result of complete absence of manurial practices at this place.

The two Estates of North Coorg, namely Chinnali at Somvarpet and Huntsey at Shanivarsante also exhibited similar association of original fresh weight with loss in fruit weight. The largest fruit of Huntsey Estate with an average weight of 162.7 g registered the highest loss of 13.5 per cent after 12 weeks' storage. From Table 33 it should be seen that this estate made the heaviest applications of nitrogenous fertilizer in the form of ammonium sulphate. The level of nitrogen fertilization may, therefore, be considered responsible for the extent of fruit development and subsequent rate of loss in weight.

(iii) *Peel content.* This character was found to vary in fruits of different orchards to a significant degree but the causative factors were neither uniform nor equally potent. In the Tithimati group, the average peel percentage of 32.79 in the fruit of Bhadrachala Estate was found to be unusually high. The conditions of water stress prevailed in that orchard during the fruit maturation period. In the other two Estates of this group peel percentage exhibited considerable variation at different sampling intervals rendering the final average less reliable for arriving at any conclusion.

The orchards of Pollibetta group were characterized by almost identical values of peel percentage regardless of their substantial differences in fruit size and percentage loss in fruit weight. On the whole, the Pollibetta Estates registered higher peel percentage than the Tithimati group, if the unusually high value of Bhadrachala Estate is discarded for obvious reasons.

The fruit of Huntsey Estate in North Coorg showed some positive effect of heavy manurial practices on the peel percentage of fruit.

(iv) *Juice content.* Fruit from these orchards also showed considerable variation in juice content. In Balmany and B & C Estates, the juice percentage showed almost reciprocal adjustments with peel percentage. Bhadrachala Estate, where the drought conditions during

fruit maturity caused excessive reduction in the juice content of fruit, registered the lowest average value of 46.84 per cent among the estates under study.

Orchards of Pollibetta group also showed marked differences in the juice content of fruit despite their non-significant differences in peel percentage.

The Craigmere Estate of this group showed the second lowest value of 49.79 per cent for juice in the whole series of orchards under study. More critical examination of the data revealed that Craigmere fruit was singularly marked by high rag content. This is the residual portion of fruit weight after taking into account the peel and juice fractions. Actually, the rag percentage for Craigmere, Muscalbora and Yemmigoondi Estates worked out as 18.44, 17.37 and 15.30 respectively, on the above basis. The behaviour of Chinnali and Huntsey Estates in North Coorg regarding juice content was of reciprocal nature with peel percentage.

In spite of such significant differences in the peel and juice content of fruit from different orchards the storage behaviour of these constituents was almost identical as the ultimate values after 12 weeks' storage fell broadly in line with their original values except for the sampling variations.

(v) *Total soluble solids in juice.* The results showed that in the Tithimati group, B & C Estate was characterised by the higher total soluble solids content of 14.21 per cent thus excelling all other orchards under study. In the Pollibetta group, Yemmigoondi Estate stood out in this character with a mean value of 13.67 per cent. The total soluble solids for Chinnali Estate of North Coorg were also significantly higher than Huntsey Estate.

The effect of storage period on total soluble solids in the fruit from different orchards was nearly of the same nature showing slight concentration during early stages of storage followed by some stabilisation of these values over the greater part of the storage period, and finally ending with a slight decline at 12 weeks. The individual orchard trends were marred by sampling variations.

(vi) *Titratable acidity.* This component of juice showed wide variation from orchard to orchard even in the beginning from 0.55 per cent in Muscalbora Estate to 0.84 per cent for B & C Estate. Between orchards of the same locality this disparity in initial acid content was also strongly marked. On the whole, the relative differences in the acidity of fruit from different orchards continued to persist throughout the storage period. For example, Muscalbora, Huntsey and Balmangy Estates which recorded the lowest values of acidity at the beginning of storage had also the lowest final mean in the same order. It

does not follow from this that the storage behaviour of fruit from all estates was identical. Chinnali Estate was outstanding in the stability of acid fraction in fruit juice during storage since from the initial value of 0.69 per cent it dropped to only 0.61 per cent at the end of 12 weeks. In most of the other orchards, drop in acidity after 8 weeks' storage was rather conspicuous. But variations in the acidity of Craigmere fruit were rather sharp and irregular leading to even a slight increase in the final average of 0.741 per cent compared with the initial value of 0.71 per cent. This may be attributed to the errors of sampling.

(vii) *Total soluble solids acid ratio.* The analysis of the data revealed that the fruit from B & C Estate and Bhadragola initially possessed almost the same T.S.S./Acid ratio of 17.4, but subsequently the fruit of Bhadragola Estate tended to preserve its blend a little better than the fruit of B & C Estate. After six weeks, these two estates once again became at par and thereafter the blend of B & C Estate broke down rapidly. Unlike these two Estates the fruit from Balmany Estate possessed a consistently higher ratio up to eight weeks whereafter the breakdown in this character was rather sudden. The fruit of Craigmere Estate regularly gave low values of T.S.S./Acid ratio, though showing prominent fluctuations from stage to stage. The fruit of Muscalbora Estate was characterised by high values of T.S.S./Acid ratio and followed nearly the same trend as the fruit of Balmany Estate.

(viii) *Ascorbic acid in juice.* The ascorbic acid content in the juice of fruit from different orchards showed that B & C Estate was favoured with the highest ascorbic acid content and this superiority was maintained throughout the storage period of 12 weeks. The second best orchard in this respect was that of Chinnali Estate whose ascorbic acid content, though comparatively low over most of the storage period, was nearly the same as in B & C Estate during the last two stages of sampling.

Against these two best orchards in ascorbic acid content the two worst orchards were represented by Huntsey Estate and Yemmigoondi Estate. Not only was the fruit of these orchards lowest in initial ascorbic acid content but the drop in their values also was more rapid during storage. Even the initial difference in the ascorbic acid content of these two orchards ultimately narrowed down like that of the two best orchards already described. The remaining four orchards of Balmany, Bhadragola, Craigmere and Muscalbora Estates were characterised by intermediate values of ascorbic acid.

(ix) *Wastage of fruit.* The most salient feature which emerged from the study of cumulative wastage in fruit of different orchards during storage at 39°-42°F was the high rate of loss in fruit from Yemmigoondi and Huntsey Estates right from the beginning, resulting in

3 and 24 per cent wastage respectively at the end of 12 weeks' storage. Judging the optimum storage of fruit by the arbitrary limit of 10 per cent wastage it would be observed that the fruit of Yemmigoondi Estate could be stored only for eight weeks whereas storage could be extended to ten weeks in Huntsey Estate. For the rest of the orchards, fruit wastage did not exceed 8 per cent even after 12 weeks.

Further critical examination of the data revealed that the fruit from B & C Estate and Muscalbora Estates did not suffer any wastage up to eight weeks in store and even thereafter the wastage percentage in their case remained low.

It would be interesting to note here that the orchards showing very high rates of fruit wastage during cold storage were incidentally the same that registered the lowest values of ascorbic acid in juice.

X. ECONOMICS OF COLD-STORAGE PRACTICE IN 'COORG' MANDARIN ORANGE

A semi-commercial trial on the cold storage of 'Coorg' mandarin orange was conducted with 50 crates of fruit of the main-season crop. The fruit was supplied gratis by the Coorg Orange Growers' Co-operative Society, Pollibetta, but its cost was accounted for at the then current market rate to work out the economics of cold-storage practice. The crates were of the standard size (65×35×35 cm) and contained 240 fruits each. In all, 12,000 fruits were stored at the optimum temperature range of 39°-42°F in one of the cold storage rooms of the Central Food Technological Research Institute, Mysore. The charges of cold storage facilities were calculated on the basis of actual rates current in commercial cold storages.

(i) *Disposal of fruit.* After 60 days of storage, a lot of 15 crates was taken out and sent to the local Mysore market for sale. The crates were opened up on the market floor. Sound fruits were sorted out and put to open bid. The extent of fruit wastage was also recorded. Ten days later, i.e., after 70 days of storage two more lots of 15 crates each were taken out from the cold store. One of these lots was disposed of in the local Mysore market in the manner described above and the other lot was despatched per passenger train for sale in the Bangalore market 87 miles away. It may be added that both these lots were removed from the cold storage room on the previous evening and the actual sales were effected in the two markets at the same time next morning. The remaining lot of five crates was marketed at Mysore after another interval of ten days making a total storage of 80 days in this case.

(ii) *Wastage of fruit.* The wastage of fruit recorded in different lots is summarized in Table 34.

Table 34. WASTAGE OF 'COORG' ORANGE DURING STORAGE IN A
SEMI-COMMERCIAL TRIAL

Market	Storage period (days)	Number of crates	Number of fruits			Wastage
			Total	Sound and sold	Damaged and rejected	
Mysore	60	15	3600	3413	187	5.2
Mysore	70	15	3600	3329	271	7.5
Bangalore	70	15	3600	3341	259	7.2
Mysore	80	5	1200	1039	161	13.4

Obviously, the wastage of fruit after 60 days of cold storage amounted to only 5.2 per cent and increased by another 2 per cent by storage up to 70 days. It was observed that fruit wastage during this period was mainly owing to the inroads of fungal pathogens like the blue mould (*Penicillium italicum* Whemer) and the green mould (*Penicillium digitatum* Sacc.). The former type was found to be more commonly responsible for this rottage. With prolonged storage of 80 days, wastage of fruit mounted to 13.4 per cent. The wastage at this end was not owing to the fungal pathogens alone, but the additional factor of

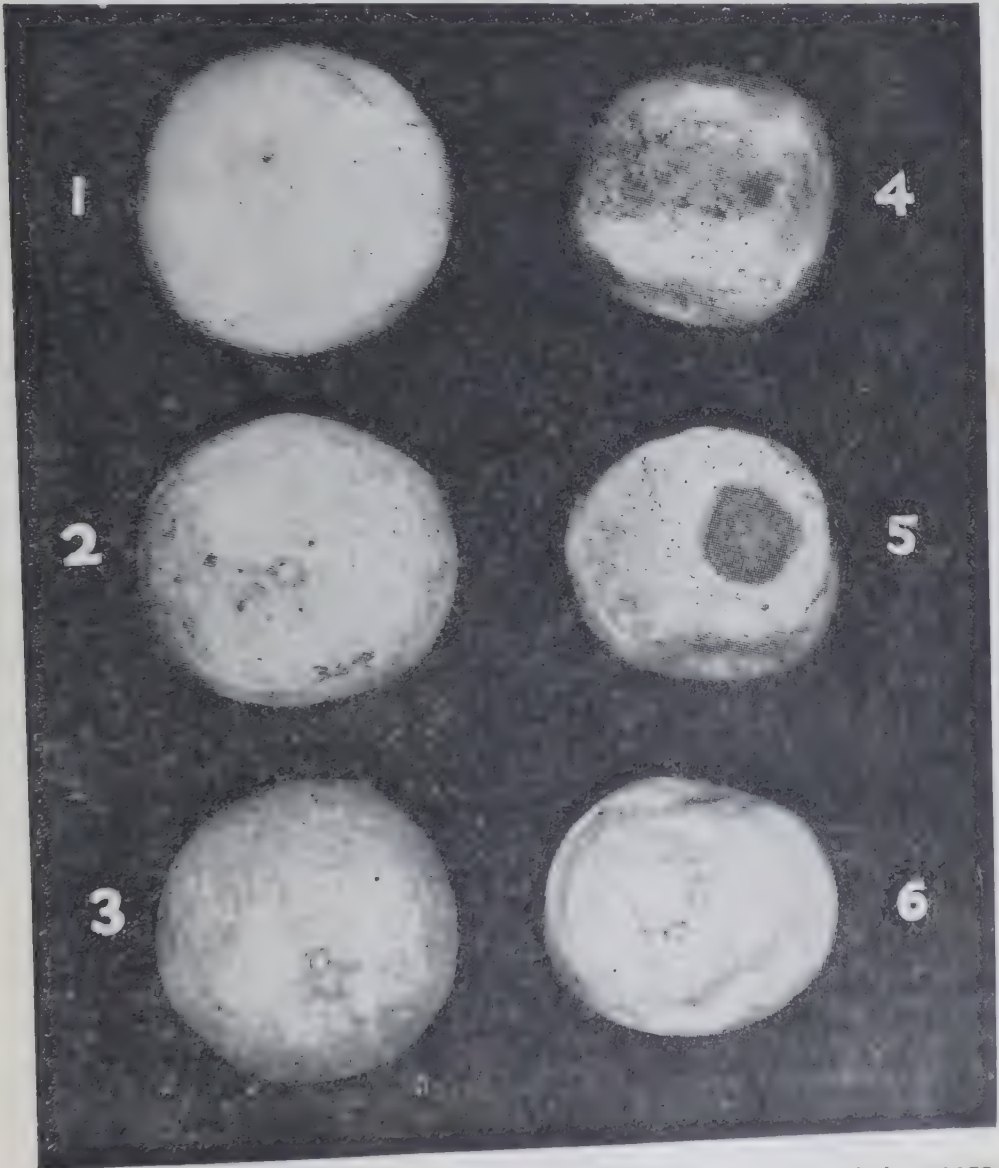


Fig. 9. Types of fruit wastage during cold storage of 'Coorg' mandarin orange.

low temperature injury had also come into play as judged from the dull appearance and subsequent browning of fruit. The various types of fruit wastage are shown in Fig. 9 in case of 'Coorg' mandarin orange. However, for comparative study the types of fruit wastage in case of 'Sathgudi' sweet orange are given in Fig. 10.

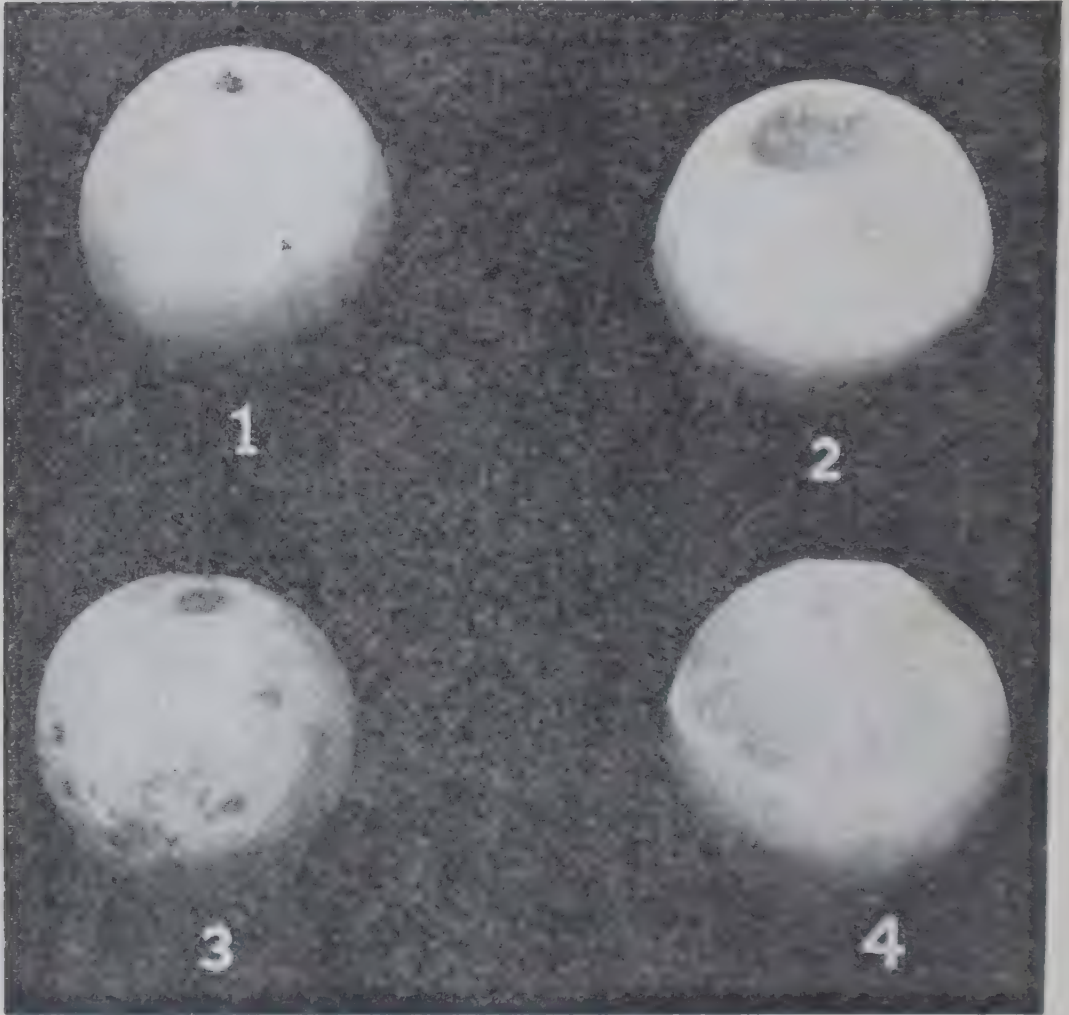


Fig. 10 Types of fruit wastage during cold storage of 'Sathgudi' sweet orange.

iii *Economics of cold storage.* A summary statement of receipts and expenditure involved in the storage and periodic marketing of fruit is given in Table 35.

In cold-storage practice all the fruit is seldom sold in one lot. Efforts are made to dispose of the fruit according to the prevailing market trends. Net profit realised from all transactions at the end of storage, therefore, gives a better idea of the economics of cold storage.

Table 35. ECONOMICS OF A SEMI-COMMERCIAL TRIAL ON THE COLD STORAGE OF 'COORG' ORANGES

Receipts		Expenditure	
Mysore market	Rs	(i) Cost of 12,000 oranges @ Rs 4 per 100	Rs 480.00
15 crates after 50 days	225.44	(ii) Packing charge	27.500
15 crates after 70 days	235.37	(iii) Transport charges (Coorg to Mysore)	25.00
5 crates after 80 days	77.75	(iv) Cold storage charges @Rs 1 per crate	50.00
Bangalore market		(v) Rly. freight and cartage charges	13.75 596.25
15 crates after 70 days	243.75	Net profit	186.06
Total	782.31	Total	782.31

practice than the individual sales. On this basis a net profit of Rs 186.06 was made on an actual investment of Rs 596.25 which worked out to 31.2 per cent. The items of receipt alone offer a good comparative idea of the anticipated income because the expenditure constitutes common and inelastic overhead charge for any venture in cold storage.

If the period market trends are taken into account it will be seen that the disposal of fruit after 70 days of storage was most profitable. Till now the wastage percentage remained well within the arbitrary economic limit of 10 per cent, and the quality of fruit was also acceptable. Disposal of fruit even after 80 days of storage was found to be as profitable as disposal after 70 days because of the higher market trends towards the fag-end of the season, although the wastage percentage was rather high (13.4 per cent). As the quality of fruit had deteriorated considerably by this time, it is somewhat more risky to keep fruit in cold storage beyond 70 days.

It was also found that between the two markets tried for the disposal of cold-stored fruit there was not much to be gained by the higher net sale proceeds realised at Bangalore market as they just covered the extra rail freight and cartage charges incurred in this transaction over the local Mysore market.

XI. GENERAL CONSIDERATIONS

Storage behaviour of oranges. As long as the fruit remains attached to the tree its transpiratory losses of moisture are made good by the parent tree. But, on harvest, this cycle of replenishment is interrupted, though the fruit still continues to lose moisture through the peel. If this loss goes on unchecked the fruit shrivels up and becomes unmarketable. For example, the 'Coorg' mandarin of the main-season crop kept at room temperature of 76°-90°F lost as much as 13.2 per cent in weight during two weeks. By prolonged storage of eight weeks this fruit was reduced to almost half the original weight.

For retarding this moisture loss and prolonging the marketability of fruit, cold storage is commercially the most important means employed. Low temperatures, no doubt, greatly curtail the rate of moisture loss during storage, yet some loss is inevitable in order to allow the fruit to carry on its life processes at a diminished rate. This minimum rate of moisture loss will, in individual cases, depend on the constitution of the fruit stored under a given set of conditions. In the present investigations, the average physiological loss in the weight of 'Coorg' mandarin of the 'main season' crop was 1.09 per cent per week. The corresponding value of weekly loss in 'Nagpur' mandarin and 'Sathgudi' sweet orange was 0.95 per cent and 1.19 per cent respectively. This clearly brings out the varietal as well as the specific differences in storage behaviour regarding loss in fruit weight. The higher rate of loss in 'Sathgudi' sweet orange in comparison with the 'Coorg' and 'Nagpur' mandarins could be attributed to the thin nature of its peel adhering more tightly to the pulp-ball. The juice content of fruit did not appear to exercise any influence in this phenomenon as the 'Sathgudi' orange contained only 52.7 per cent juice as against 56.2 per cent in the 'Nagpur' mandarin of the main-season crop at the commencement of storage.

The role of peel in regulating the physiological losses, of which moisture loss is most predominant, was brought out even more prominently by the relative rate of loss in the fruit of the main-season and rainy-season crops of the same variety. The fruit from the main-season crop of 'Coorg' mandarin suffered a weekly loss of 1.09 per cent as against 2.13 per cent in the fruit of rainy-season crop. The corresponding losses in 'Nagpur' mandarin were 0.95 and 1.55 per cent respectively, for the fruit of these two cropping seasons. The explanation is to be sought in the influence of the seasonal factor. Favourable conditions for rapid fruit development during the rainy-season lowered the peel percentage besides materially modifying its cell

structure. Under such conditions the individual cells of peel are expected to be large and thin-walled with high moisture content. The moisture regulating mechanism in the peel of rainy-season fruit could not, therefore, be as efficient as in the peel of the main-season fruit.

During storage the loss of moisture from the peel is continuously replenished by the movement of the moisture from the pulp within. It has been found that if the fruit was stored at or about the optimum storage temperature the adjustment of moisture relationship between the peel and juice was nearly perfect over a considerable length of storage period, and their relative proportions did not deviate much from their original values. At higher storage temperatures, however, when the physiological losses were high, the peel percentage steadily increased and the juice percentage showed a corresponding fall. Although the fruit looked quite attractive during the later stages of storage at higher temperatures, it actually became non-juicy from within owing to the high rate of moisture loss. The peel maintained itself at the cost of the pulp. This was true for the fruit of both the species studied.

It is noteworthy that the periodic losses in fruit weight were not uniform during the storage period. The fortnightly loss was found to increase progressively with the advance of storage period. This suggested that some physico-chemical changes were concurrently going on in the fruit, particularly in the peel, which lowered its resistance to the loss of moisture. It is highly suggestive that protoplasmic factors are also involved in the control of moisture loss.

The physiological losses in fruit weight during storage consist of the loss of moisture and the consumption of carbohydrates in respiration. Some volatile substances like the essential oils are also given off but quantitatively this loss is not of much significance.

Total titratable acidity in the juice followed the same trend as the other soluble solids. The behaviour of ascorbic acid, the most important constituent of fruit, though generally similar to the total acidity, varied in significance at different stages of storage.

Ascorbic acid and the storage life of fruit. In 'Coorg' mandarin of the main-season crop, stored at 35°-38°F, 39°-42°F, 42°-45°F and 47°-50°F for fourteen weeks, the average weekly fall in ascorbic acid content worked out to 0.84, 0.65, 0.68 and 0.34 mg/100 ml juice respectively after eliminating the concentration effects due to the loss of moisture. There was thus less loss of ascorbic acid at higher storage temperatures. On the contrary, Hamburger and Joslyn (1941) working on the retention of ascorbic acid in canned citrus juices found higher rates of destruction of ascorbic acid with rising temperatures above 50°F. It is, therefore, reasonable to assume that

the preservation of ascorbic acid in living fruits stored at low temperatures is not as simple a problem as in canned juices. Ascorbic acid seems to be somehow involved in metabolic processes of fruit characteristic of low temperature storage, and it is ultimately destroyed at an accelerated rate.

Increased loss of ascorbic acid during storage of fruit at unfavourably low temperatures suggests that ascorbic acid is probably mobilized in some form of defence mechanism. With the onset of low temperature injury to the protoplasm, the production of auxins may be accelerated. The enzymatic destruction of auxins has been shown in peas by Galston and Baker (1951). The destructions of auxins can be altered by a competitive inhibitor or the reaction. Brauner and Brauner (1954) have shown ascorbic acid to be a good example of this type of inhibitor as it can be readily oxidized and thus inhibits auxin destruction by competing for the auxins in the reaction. The utilization of ascorbic acid in this chain of reaction is very probable and needs confirmation.

The decline in the ascorbic acid content of mandarin stored at 35°-38°F occurred after six weeks of storage, while this event was noted after 14 weeks in 'Sathgudi' sweet orange. This differential behaviour of the two species under study may be due to the absence or presence of some protective principle of ascorbic acid. According to Somogyi (1944), citrus juices contain an active principle which inhibits the destruction of ascorbic acid and protects it from the action of ascorbinase.

The high loss in ascorbic acid during storage at the lowest temperature of 35°-38°F was found to be associated with heavy wastage of fruit. This was noted in the 'Coorg' and 'Nagpur' mandarins of the main-season crop as well as in the 'Sathgudi' variety of sweet orange. Similar relationship between the rate of ascorbic acid destruction and fruit wastage was reported by Tindale (1950). Working on a stock-scion relationship he observed that 'Navel' orange on Citronelle stock, which showed more wastage from *Penicillium* moulds than fruit from other stocks, suffered greater loss in ascorbic acid during storage.

Further evidence on the protective role of ascorbic acid in controlling fruit wastage during storage was obtained on orchard variability. Out of the eight orchards under investigation, the fruit from Yemmigoondi and Huntsey Estates could not be stored for more than eight weeks as against 12 weeks in other orchards. The fruit of these two orchards which displayed poor keeping-quality was characterised by the lowest value of ascorbic acid in juice. Metlickii and Cehoms-kaja (1949) had shown that ascorbic acid content of citrus fruits determined their resistance to physiological breakdown during storage.

They suggested that vitamin C content of citrus fruits could be taken as an indication of their resistance to decay in storage and that the selection of new varieties for high vitamin C content would yield forms with an increased storage life.

The present findings on the significance of ascorbic acid in the storage of citrus fruits are not only in full agreement with those of the previous workers but show further that the unusual decline in its value at any stage during storage at low temperatures can be taken as a warning of the impending storage disorder. Full import of this small but vital constituent of citrus fruits would only be appreciated with further accumulation of evidence on its role in various phenomena of plant growth and fruit storage.

Optimum storage temperature. The optimum storage temperature is one that ensures the longest life of fruit with minimum wastage and most satisfactory preservation of fruit quality. According to Barker (1930), the term 'wastage' is used to include not only those conditions of over-ripeness or disease in which the appearance, texture and flavour of fruit are markedly abnormal but also the less extremely conditions in which only the appearance is affected. From the economic stand-point, wastage of all types in orange should not be more than 10 per cent in fruit number. Such a limit on the loss of flavour during storage is also arbitrary but variable depending on several considerations.

The progress of wastage and the deterioration in flavour may not, however, be well co-ordinated and the one may outstep the other. Trout *et al.* (1938), observed that the storage life of oranges was terminated by the loss of palatability in storage while Hall (1938) emphasized that fungal wastage and rind disorders set a limit to the storage life before loss of palatability became important.

The present investigations on the 'Coorg' and 'Nagpur' mandarins of the main-season crop showed that off-flavour set in earlier than the occurrence of 10 per cent wastage. This was also found to be true in 'Sathgudi' sweet orange. On the contrary, the rainy-season fruit of 'Coorg' and 'Nagpur' mandarins succumbed more readily to the attack of *Penicillium* rots. Thus, the 10 per cent wastage limit was reached much earlier in their case than the loss of flavour during storage.

The flavour of fruit is a very subtle character and hard to define. Apart from the organoleptic test, the sugar-acid ratio is commonly employed to give this character a quantitative expression. Australian workers have preferred to use the acid content alone as the criterion of taste. In the present investigations, sugar-acid blend as indicated by the total soluble solids/acid ratio was employed for this purpose. The critical ratio of T.S.S./acid for each variety of orange had to be

fixed separately depending on the original values of total soluble solids and titratable acidity in juice. The taste and flavour of cold-stored fruit, as generally accepted by the consumer, was also taken into account in fixing this critical ratio. Based on these criteria and assumptions, the maximum storage life of oranges, as determined by storage at different temperature ranges in the present investigations, is given in Table 36.

Of the four storage temperatures employed, the maximum storage life of 'Coorg' and 'Nagpur' mandarin oranges of the main-season crop was found to be 12 and 14 weeks respectively, at 39°-42° F. This optimum temperature range agrees well with the findings of Cheema *et al.* (1937) and Karmarkar and Joshi (1942) who reported 40°F to be the best storage temperature for 'Nagpur' mandarins. For 'Coorg' mandarin, however, the present study attempts to determine its storage behaviour at different temperatures.

For 'Desi' mandarin grown in northern India in the Punjab, Khan (1941), Lal Singh and Hamid (1942) and Bajwa and Kirpal Singh (1945) reported 36°-39°F as the optimum storage temperature. The difference in temperature requirements of mandarins grown in north and south India is very likely owing to the different climatic conditions experienced by the fruit during maturation period. The cold winters of the north so conditioned the fruit that it stayed better at a slightly lower storage temperature.

The influence of climatic factors on storage temperature requirement is again brought out with equal force in sweet orange. For instance, 'Sathgudi' sweet orange grown in Andhra Pradesh in south India had the longest storage life of 16 weeks at 42°-45° F, whereas the sweet orange varieties of northern India grown in the Punjab stored best at 36°-39°F. The 'Mosambi' orange grown in Bombay State (now Maharashtra) was reported by Cheema and Karmarkar (1942) to require an intermediate storage temperature of 40°F.

Thus, there is sufficient evidence of the varying temperature requirements for the storage of oranges produced in different climatic regions of India. The gradient of optimum storage temperature follows generally the gradient of low winter temperatures experienced by the fruit of different varieties during their maturation period.

A word may be said about the optimum storage temperature requirements of 'Coorg' and 'Nagpur' mandarins of the rainy-season crop. These fruits are comparatively more acidic in taste. Their storage life is brought to an early end by *Penicillium* rot before any serious development of off-flavour. Since the growth of *Penicillium* moulds is effectively checked by relatively low temperatures, the lowest temperature range of 35°-38° F gave the best results. The maximum storage life of 'Coorg' and 'Nagpur' mandarins of the rainy-

season crop was found to be six and eight weeks respectively at this temperature.

In determining the maximum storage life and the optimum storage temperature only two desiderata, viz. T.S.S./Acid ratio and the wastage have been given in Table 36. In fact, the period changes in other characters of fruit quality were also taken into consideration in arriving at these conclusions. It is encouraging to note that at the optimum storage temperatures indicated above, the juice of the fruit and its ascorbic acid value were generally found to be slightly better than at the lower storage temperatures. At higher storage temperatures than the optimum one, the juice was invariably low.

Table 36. THE MAXIMUM STORAGE LIFE OF FRUIT, ITS PALATABILITY AND CUMULATIVE WASTAGE IN SOME ORANGE VARIETIES STORED AT DIFFERENT TEMPERATURES

Variety and storage temperature	Storage life (weeks)	T.S.S./Acid ratio (palatability)	Wastage (%)	Storage life limited by
'Coorg' mandarin orange (main-season)				
		*22.0	**10	
35°-38°F	8	20.0	0	Low temp. injury
39°-42°F	12	21.5	4	Off-flavour
42°-45°F	10	22.4	3	Off-flavour
47°-50°F	8	19.5	1	Loss of juiciness
'Coorg' mandarin orange (rainy-season)				
		*17.0		
35°-38°F	6	15.3	6	<i>Penicillium</i> rots
39°-42°F	4	16.0	10	" "
42°-45°F	2	14.5	2	" "
47°-50°F	2	14.1	2	" "
'Nagpur' mandarin orange (main-season)				
		*30.0		
35°-38°F	10	29.1	4	Low temp. injury
39°-42°F	14	28.4	8	Off-flavour
42°-45°F	8	30.2	3	Off-flavour
47°-50°F	8	27.6	4	Off-flavour
'Nagpur' mandarin orange (rainy-season)				
		*14.0		
35°-38°F	8	12.6	5	<i>Penicillium</i> rots
39°-42°F	6	11.5	10	" "
42°-45°F	+5	11.2	8	" "
47°-50°F	4	11.0	8	" "
'Sathgudi' sweet orange				
		*30.0		
35°-38°F	12	29.4	0	Low temp. injury
39°-42°F	+13	28.8	4	Off-flavour
42°-45°F	16	28.7	4	Off-flavour
47°-50°F	14	27.7	6	Loss of juiciness

+ by interpolation

*critical T.S.S./Acid ratio

**critical wastage percentage

Some explanation is necessary for 'no wastage' noted at 35°-38°F in Table 36 against 'Coorg' orange of the main-season crop and 'Sathgudi' orange. It was given in the remarks column that the storage life at this temperature terminated due to low temperature injury. In reality, the low temperature injury had actually taken place during the period indicated as maximum storage life but remained latent. It was first evidenced by the low T.S.S./Acid ratio owing to the rapid loss of total acidity in juice. The ascorbic acid also showed a decline along with the total acidity. The fruit appeared normal externally at this stage but subsequently it developed all the characterised signs of low temperature injury on the rind. The wastage mounted high, exceeding the values recorded at other storage temperatures.

Development of orange colour during storage. The tropical conditions prevailing in south India do not favour the proper development of orange colour in sweet oranges. Even after attaining full maturity, the fruit maintains various shades of green hue in combination with yellow. Since the orange is particularly prized for its attractive colour apart from its nutritive value, studies were made on 'Sathgudi' sweet orange to find a suitable temperature or temperature combinations which could cause proper colour development during storage.

It was observed that 'Sathgudi' sweet orange stored at 39°-42°F continued to look pale-green up to ten weeks and showed slight turning to yellow thereafter. The intensification of yellow colour was very slow even at 42°-45°F. Storage at 47°-50°F was very conducive to the rapid intensification of yellow colour but the change to orange colour was meagre and slow. The most favourable temperature for colour development was found to be 52°-55°F, where the change from pale-green to good yellow was fast leading to the appearance of fair orange colour after storage of four weeks only. Further storage helped to deepen this hue.

From the colour change under different temperatures it would appear that up to a certain range of temperature only yellowing would occur because of the increase in manifestation of the carotenoid pigments, and the development of red pigment (anthocyanin)—the determining constituent of orange colour—would take place only beyond a certain minimum temperature. This critical temperature seems to be 45°F.

Since prolonged storage at 52°-55°F caused excessive losses in fruit weight and thereby reduced its storage life, this temperature was utilized in another experiment for an initial holding for four weeks only. The fruit thus conditioned was transferred to 42°-45°F, which had been found to be the optimum storage temperature for this variety. It was revealed that, despite the higher physiological losses in fruit weight at this temperature combination during the first 14 weeks of

storage, the ultimate loss after 20 weeks' storage was only 16.1 per cent as compared with 23.8 per cent in the case of fruit continuously stored at 42°-45°F. The attractive orange colour obtained at this temperature combination was an additional advantage of commercial value. The colour change was so perfect that it was hard to convince the people in trade that the fruit so treated was really the same 'Sathgudi' sweet orange. It could easily be mistaken for a highly coloured orange imported from the northern States of India.

Physiologically, this temperature treatment for colour development is similar in effect to the 'qualling' or 'sweating' done in the grove under ordinary atmospheric temperatures (Powell, 1930; Bates, 1934; Palestine Orange Shipments, 1933) or at a controlled temperature of 70°F (Friend and Bach, 1932; Hawkins, 1921).

Post-storage behaviour of fruit. The ultimate utility of cold-storage practice lies in the fact that the stored fruit should be able to reach the consumer in sound condition. Once the fruit is out of the cold-storage it has to stay at ordinary atmospheric temperature for a few days while it is moving through the common channel of trade. Failure of the fruit to withstand such conditions during the short post-storage interval may lead to heavy wastage of fruit and enormous financial loss.

During these investigations it was found that the extent of damage done to 'Sathgudi' sweet orange during storage at 35°-38°F could not be assessed at the time of removing the fruit from the cold store. The fruit looked quite normal but the damage was already done. This latent injury was manifested in full measure shortly after the fruit was exposed to the ordinary atmospheric conditions. The fruit collapsed, became dull brown and developed off-flavour. On the contrary, the fruit stored at the optimum temperature range of 42°-45°F did not show much signs of distress or deterioration when taken out of the cold store. It kept well in appearance and taste during the experimental post-storage period of seven days. In short, the post-storage behaviour of fruit was a bolder manifestation of the earlier physico-chemical changes initiated in it during cold storage. The optimum storage temperature where the pace of degenerating processes was slow, therefore, automatically ensured good post-storage life of fruit.

The 'Coorg' and 'Nagpur' mandarins of the main-season crop, after storage at 39°-42°F for 12 weeks, were found to have post-storage life of four to five days as compared with six to seven days in 'Sathgudi' sweet orange stored at 42°-45°F for 16 weeks.

Non-refrigerated storage. In a tropical country like India the storage of oranges under ordinary conditions of temperature and humidity without chemical or mechanical aid is practically impossible.

'Coorg' mandarins of the main-season crop, when stored at room temperature of 76°-80°F and relative humidity 37-62 per cent, were reduced to about half their original fresh weight in eight weeks. The excessive loss of moisture caused shrivelling of fruit and rendered it non-juicy. The percentage of fruit wastage did not, however, go high. Thus, there was more of desiccation than the decay of fruit itself. The wastage of low and advanced changes in the physico-chemical composition of fruit at room temperature did not warrant its keeping for more than four weeks. The flavour, up to this time, was good and the ascorbic acid remained high.

The ascorbic acid of fruit stored at room temperature increased on percentage basis. Even in terms of absolute quantity per fruit, it did not suffer much change. This behaviour of ascorbic acid is in contrast to the 'total acidity' which remained nearly the same on percentage basis but declined in absolute quantity per fruit.

In view of the stability of ascorbic acid at room temperatures it would be worthwhile to extend the storage life of fruit under ordinary conditions by adopting suitable means to curtail the moisture loss. This is particularly important when facilities, for refrigerated storage in India are so scarce.

Cropping season in relation to fruit quality and storage life. The 'Coorg' and 'Nagpur' mandarins produce two crops a year. Some trees flower in January-February to ripen fruit during the rainy-season, while others flower in June-July to be ready for harvest during the winter months. The former is known as the rainy-season crop and the latter as the main-season crop. The rainy-season crop is commercially less important than the main-season crop. Its contribution to the total annual production is only 10 per cent in 'Coorg' mandarin and 30 per cent in 'Nagpur' mandarin.

In both cases, the fruit of the main-season crop is superior in quality to that of the rainy-season crop owing to higher content of total soluble solids and better flavour. It is also more attractive in colour and form. Its keeping-quality and storage life are also decidedly better than the fruit of the rainy-season crop.

The fruit of the rainy-season crop, though generally poor in quality, showed marked varietal differences. The 'Nagpur' mandarin of the rainy season was better in keeping quality than the 'Coorg' mandarin of the same season. The reason for this difference could be traced down to the ripening of 'Nagpur' mandarin after the close of the rainy-season when the weather became comparatively dry and more favourable for proper maturity. This fruit, although strongly acidic in taste and inferior in quality in comparison with the fruit of the main-season crop, is exported to the distant consuming markets in the country, notwithstanding its high wastage during transit. On

the other hand, the 'Coorg' mandarin of the rainy-season is very poor in keeping-quality as it is ready for harvest early and has often to be gathered during the torrential monsoon rains. In the present investigations, this fruit recorded 40 per cent wastage in number and 20.5 per cent loss in weight during storage of two weeks at room temperature. No wonder, therefore, that the growers often leave this crop unpicked for want of its profitable disposal.

Orchard variability. Even in a small State like Coorg (now district of Mysore State), the fruit of different plantations enjoys varying reputation. Some orchards are acclaimed as producers of high quality fruit while some are tabooed for the poor keeping-quality of their produce.

To verify these facts and get an idea of the extent of orchard variability in these important aspects, eight different orchards spread all over the important orange-growing areas of the State were marked out. The fruit of each orchard was picked under personal supervision and subjected to detailed studies.

Some interesting features have emerged as a result of these investigations. The fruit from Muscalbora Estate, renowned for its sweetness, did not actually have high sugar content but was characterized by low acid value. Its flavour as well as the ascorbic acid content remained well preserved in cold storage. Fruit wastage was nil up to eight weeks, and only 7 per cent after 12 weeks.

The fruit of Huntsey Estate, ill-reputed for its poor keeping-quality, actually showed high wastage of the order of 24 per cent after 12 weeks' storage. Wastage in Yemmigoondi Estate was also high. On account of high fruit wastage in these two orchards the optimum storage life of their fruit was found to be eight weeks only as compared with 12 weeks for the rest of the orchards. The analytical data showed that fruit of both these orchards had a common feature of the lowest initial ascorbic acid which further dropped rapidly during cold storage.

On the contrary, in B & C Estate, where best cultural and manurial practices were in vogue, the fruit showed the highest value of ascorbic acid initially as well as during the entire storage period. It also registered the lowest wastage of 6 per cent after 12 weeks. Balmany Estate was the next best orchard in these respects.

One cardinal point that emerges from these studies is that the ascorbic acid of orange is vitally linked with its storage life.

Besides the ascorbic acid content and storage life, the fruit of these orchards was at variance in several other important features of fruit quality. The highest peel percentage was found in the fruit of Bhadravola Estate, which could be attributed to the conditions of water stress prevailing at that place during the fruit maturation period.

The apparent effect was the lowest juice content, but it was reflected in a better sugar-acid blend which preserved well during storage. The minimum variation in T.S.S./Acid ratio was recorded in the fruit of Chinnali Estate due to the stability of acid fraction in the juice. It may be mentioned here that the cultural and manurial practices at this estate were very well balanced with more emphasis on the addition of humus than on the application of ammonium sulphate. Notable features of the fruit of Craigmore Estate were its highest rag content, high acidity, and the lowest T.S.S./Acid ratio during storage. No manurial schedule, whatsoever, was being followed there.

Orchards also varied in fruit size, the local agro-climatic conditions had an over-riding effect on this character. All the three estates of Tithimati locality produced fruit of smaller size as compared with the three estates of Pollibetta locality. The largest fruit size was recorded in case of an estate at Shanivarsante in North Coorg.

A high positive correlation was recorded between fruit size and the rate of its physiological loss. In other words, larger the fruit more the loss per unit weight. It was true both for different localities and different orchards in the same locality.

Quite the reverse relationship was obtained when the fruit of different size grades from the same tree was employed. In case of 'Coorg' mandarin of rainy-season crop the average fortnightly loss for 'large', 'medium' and 'small' fruits worked out to 4.26, 5.20 and 6.12 per cent. A weak but similar trend was visible in the main-season crop also. The 'large' and 'medium-sized' fruits of 'Sathgudi' sweet orange showed similar results from the same tree.

The discrepancy in the behaviour of fruit of different sizes from different orchards and the fruit of different size grades from the same tree may be accountable to the different operative factors. In the former case the agro-climatic and cultural factors play a dominant role whereas in the latter the internal competition between units on the same tree is involved. The type of reaction put up by the fruit may be different in these cases. The elucidation of these phenomena could be obtained through a detailed study of the physiology of fruit growth with particular reference to cell structure and composition of peel.

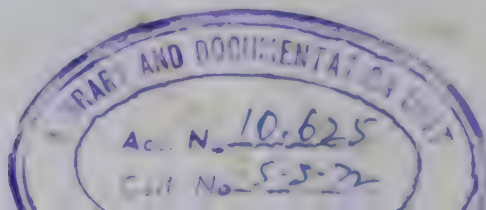
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